



US011466752B2

(12) **United States Patent**  
**Ochi et al.**

(10) **Patent No.:** **US 11,466,752 B2**  
(45) **Date of Patent:** **Oct. 11, 2022**

(54) **TRANSMISSION BELT AND CONTINUOUSLY VARIABLE TRANSMISSION, METHOD FOR DESIGNING ELEMENT, AND METHOD FOR PRODUCING ELEMENT**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 275 days.

(21) Appl. No.: **16/762,344**

(22) PCT Filed: **Dec. 7, 2018**

(86) PCT No.: **PCT/JP2018/045014**

§ 371 (c)(1),  
(2) Date: **May 7, 2020**

(87) PCT Pub. No.: **WO2019/112026**

PCT Pub. Date: **Jun. 13, 2019**

(65) **Prior Publication Data**

US 2020/0300335 A1 Sep. 24, 2020

(30) **Foreign Application Priority Data**

Dec. 7, 2017 (JP) ..... JP2017-235552

(51) **Int. Cl.**  
*F16G 5/16* (2006.01)  
*B21D 53/14* (2006.01)  
*F16H 9/18* (2006.01)

(52) **U.S. Cl.**  
CPC ..... *F16G 5/16* (2013.01); *B21D 53/14* (2013.01); *F16H 9/18* (2013.01)

(58) **Field of Classification Search**  
CPC .... *F16G 5/16*; *F16G 5/18*; *F16H 9/24*; *F16H 9/125*; *F16H 2061/66295*

(Continued)

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

3,016,755 A \* 1/1962 Dittrich ..... *F16G 5/18*  
474/201  
3,364,767 A \* 1/1968 Bredschneider ..... *F16G 5/18*  
474/245

(Continued)

**FOREIGN PATENT DOCUMENTS**

JP 2000-213609 A 8/2000  
JP 2010-023075 A 2/2010

(Continued)

**OTHER PUBLICATIONS**

International Search Report for PCT/JP2018/045014 dated Mar. 12, 2019.

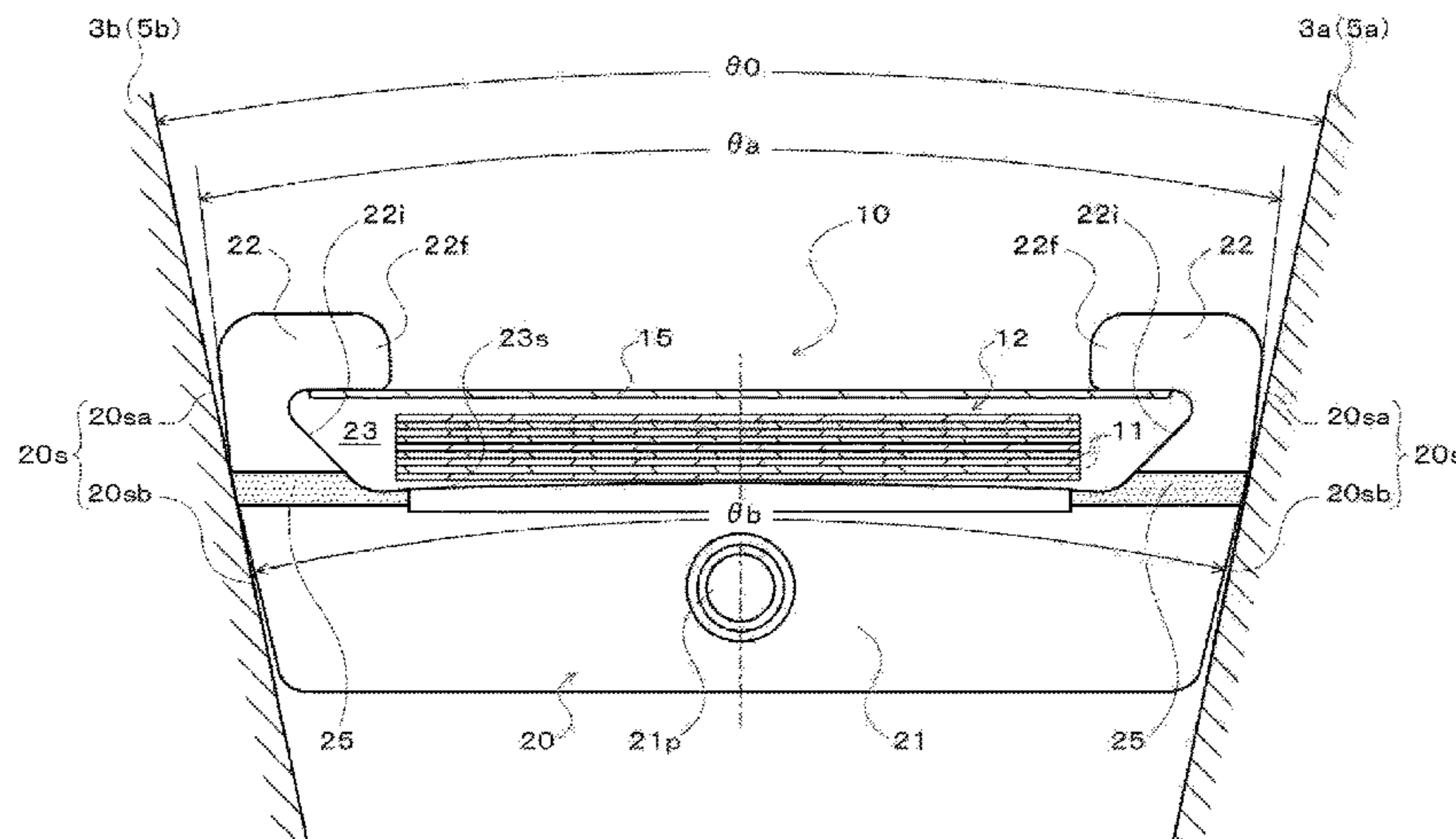
*Primary Examiner* — Henry Y Liu

(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

(57) **ABSTRACT**

Elements of a transmission belt wound around pulleys of a continuously variable transmission each include a body part, a pair of pillar parts, and a pair of side surfaces. The pair of side surfaces each include a first side surface formed on a corresponding one of the pillar parts; and a second side surface formed so as to continue from the first side surface, and located more on an inner circumference side than the first side surface. A pair of the first side surfaces each are

(Continued)



formed so as to be inclined toward an inner side of a corresponding one of the pillar parts with respect to an extending direction, from an inner circumference side to an outer circumference side of a ring, of a corresponding one of the second side surfaces continuing from the first side surface, and a pair of the second side surfaces is formed such that the second side surfaces are spaced farther apart from each other as the second side surfaces extend from the inner circumference side to the outer circumference side, and that an angle formed between the pair of the second side surfaces is larger by 0.2 to 0.8 degrees than an opening angle of V-shaped grooves of the pulleys.

**7 Claims, 17 Drawing Sheets**

(58) **Field of Classification Search**

USPC ..... 474/242  
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,916,709 A \* 11/1975 Steuer ..... F16H 9/24  
474/201  
4,545,779 A \* 10/1985 Sakakibara ..... F16G 5/18  
474/201  
4,552,549 A \* 11/1985 Hattori ..... F16G 5/16  
474/204  
4,560,371 A \* 12/1985 Hattori ..... F16G 5/16  
474/201  
4,618,338 A \* 10/1986 Rattunde ..... F16H 9/24  
474/245  
4,631,042 A \* 12/1986 Rattunde ..... F16G 5/18  
474/8  
4,795,406 A \* 1/1989 Dittrich ..... F16H 9/24  
474/201  
4,813,920 A \* 3/1989 Inukai ..... F16G 5/166  
474/240  
4,900,295 A \* 2/1990 Tani ..... F16G 5/06  
474/167  
4,915,677 A \* 4/1990 Simon ..... F16G 5/16  
474/244  
5,004,450 A \* 4/1991 Ide ..... F16H 9/125  
474/242  
5,328,412 A \* 7/1994 Durum ..... F16H 55/56  
474/8  
5,792,013 A \* 8/1998 Heinrich ..... F16G 5/18  
474/8  
6,283,882 B1 \* 9/2001 Nonaka ..... F16G 5/166  
474/201  
6,416,433 B1 \* 7/2002 Linnenbrugger ..... F16H 9/125  
474/8

6,440,024 B1 \* 8/2002 Kobayashi ..... F16G 5/163  
474/245  
6,652,403 B2 \* 11/2003 Drees ..... F16H 9/125  
474/201  
6,811,507 B2 \* 11/2004 Baumann ..... B21L 15/005  
474/215  
6,926,631 B2 \* 8/2005 Brandsma ..... F16G 5/16  
474/8  
7,037,225 B2 \* 5/2006 Takagi ..... F16H 55/563  
474/8  
7,874,952 B2 \* 1/2011 Tada ..... F16G 5/18  
474/215  
7,951,032 B2 \* 5/2011 Yagasaki ..... F16H 55/38  
474/260  
8,647,223 B2 \* 2/2014 Kuwabara ..... F16G 5/16  
474/242  
9,279,475 B2 \* 3/2016 Sumida ..... F16H 9/18  
2002/0045505 A1 \* 4/2002 Yoshida ..... F16G 5/16  
474/240  
2002/0052261 A1 \* 5/2002 Kanokogi ..... F16G 5/163  
474/201  
2003/0144097 A1 \* 7/2003 Brandsma ..... F16G 5/16  
474/69  
2005/0170926 A1 \* 8/2005 Aoyama ..... F16G 5/16  
474/237  
2005/0187057 A1 \* 8/2005 Lou ..... F16G 5/18  
474/245  
2005/0221938 A1 \* 10/2005 Yoshida ..... F16H 55/56  
474/201  
2007/0072721 A1 \* 3/2007 Takagi ..... F16G 5/16  
474/201  
2007/0117663 A1 \* 5/2007 Van Der Leest ..... F16H 55/56  
474/201  
2007/0232430 A1 \* 10/2007 Yasuhara ..... F16G 5/18  
474/215  
2008/0274848 A1 \* 11/2008 Van der Leest ..... F16G 5/16  
474/201  
2009/0082148 A1 \* 3/2009 Van Der Leest ..... F16H 9/125  
474/166  
2009/0118042 A1 \* 5/2009 Rothenbuhler ..... F16H 9/24  
474/8  
2009/0280940 A1 \* 11/2009 Toyohara ..... F16G 5/16  
474/242  
2010/0004084 A1 \* 1/2010 Fan ..... F16G 5/20  
474/242  
2010/0227721 A1 \* 9/2010 Kato ..... F16G 5/16  
474/242  
2016/0319917 A1 \* 11/2016 Van der Meer ..... F16G 5/16  
2019/0154112 A1 \* 5/2019 Ochi ..... F16G 5/16

FOREIGN PATENT DOCUMENTS

JP 2017-180784 A 10/2017  
WO 2005/019684 A1 3/2005  
WO 2017/138217 A1 8/2017

\* cited by examiner

FIG. 1

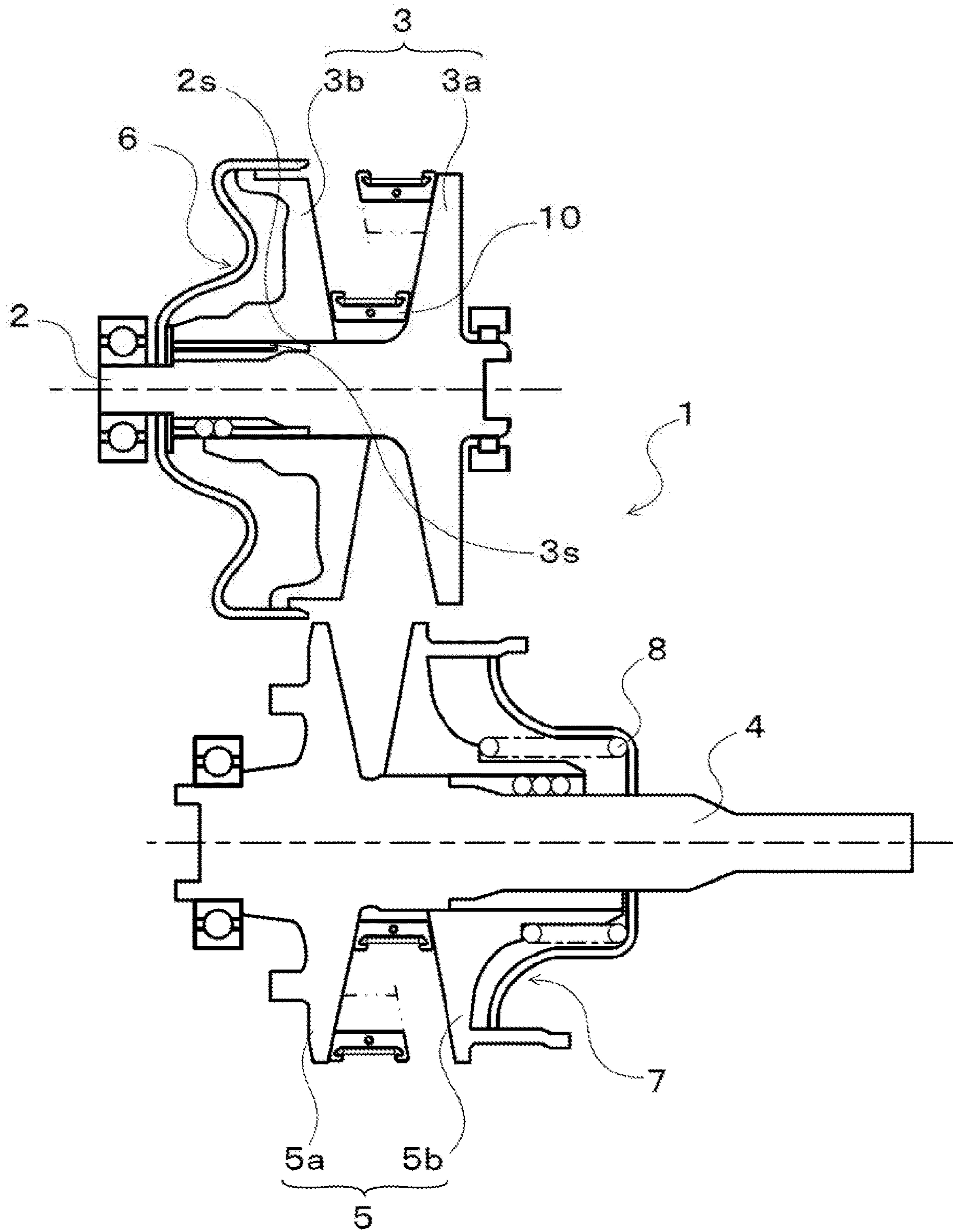


FIG. 2

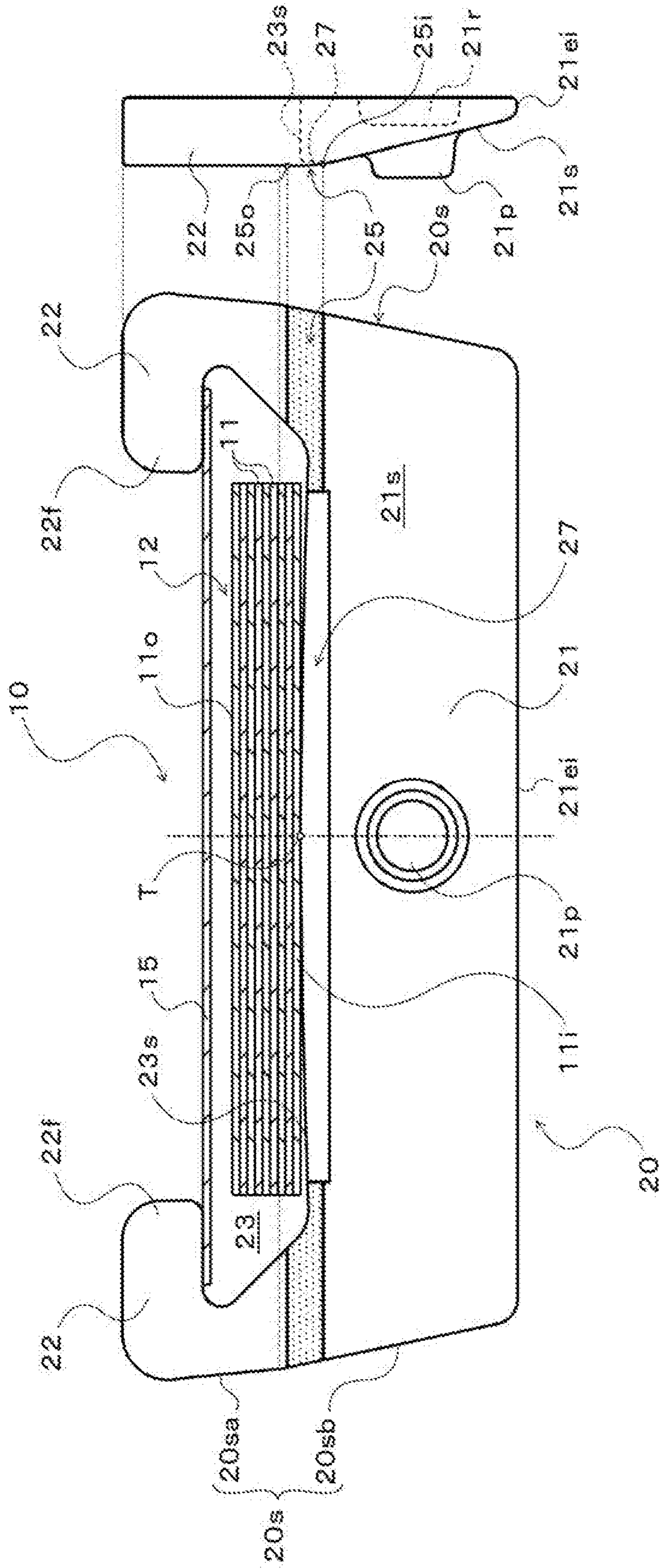


FIG. 3

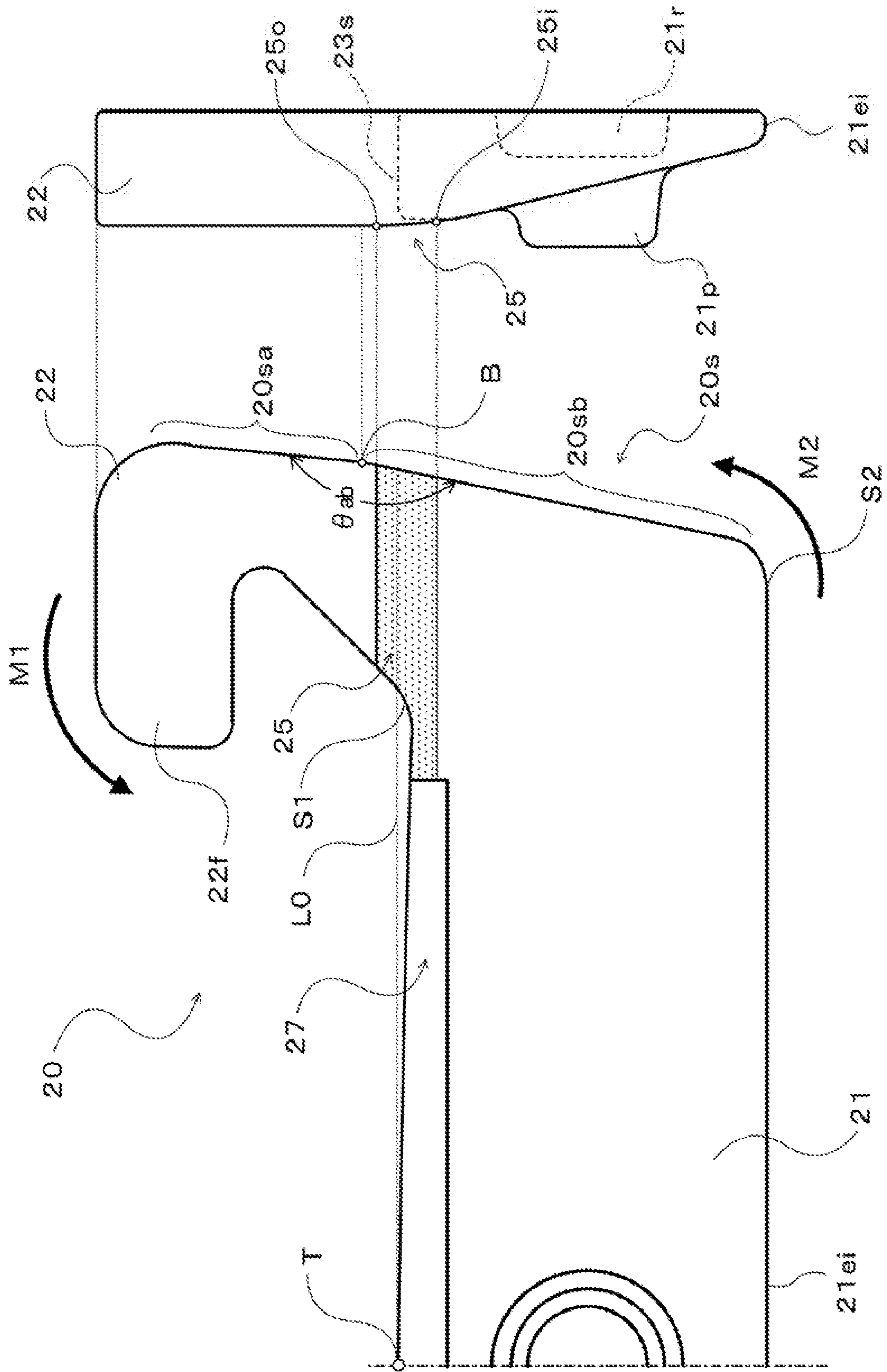


FIG. 4

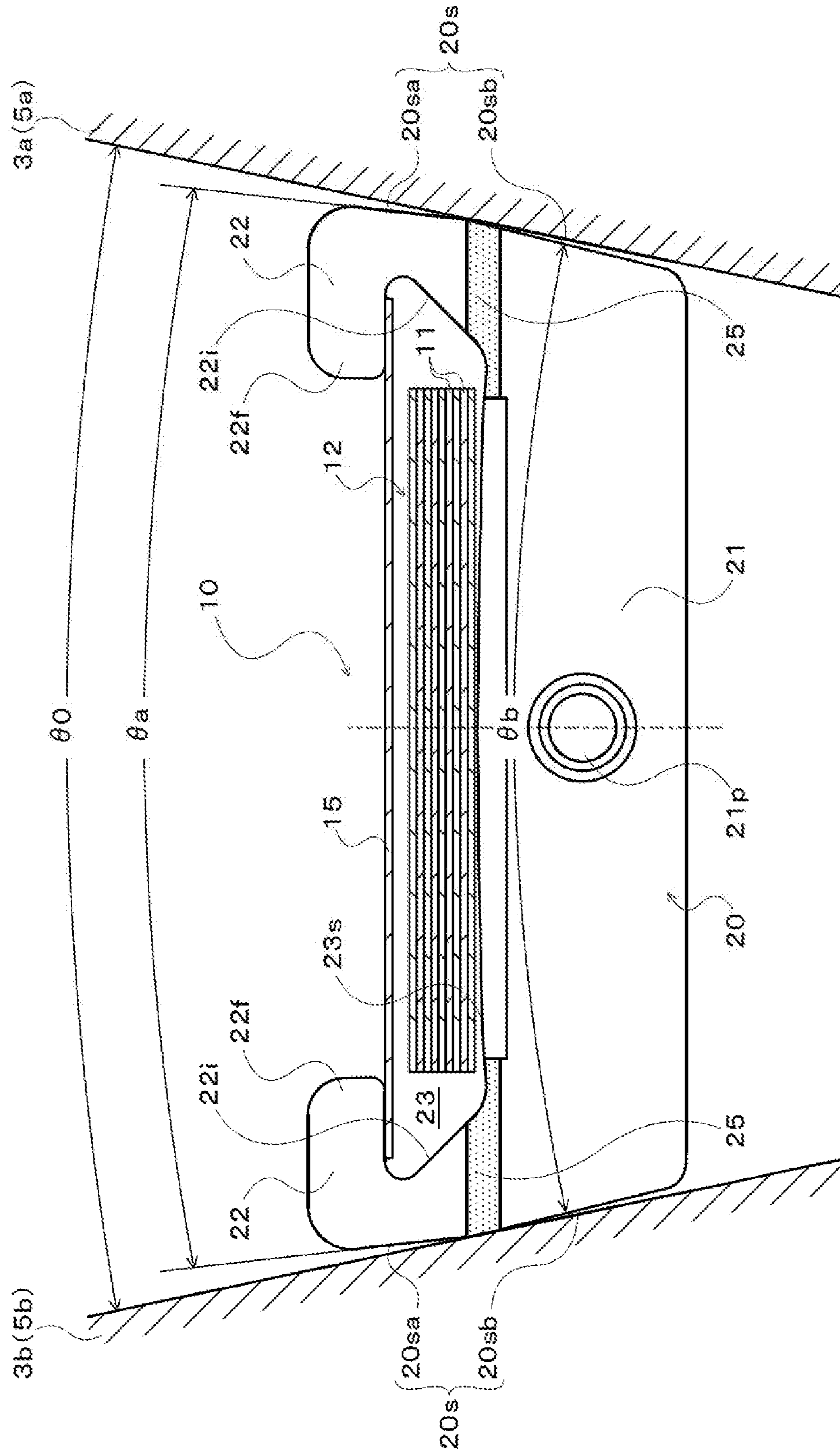


FIG. 5

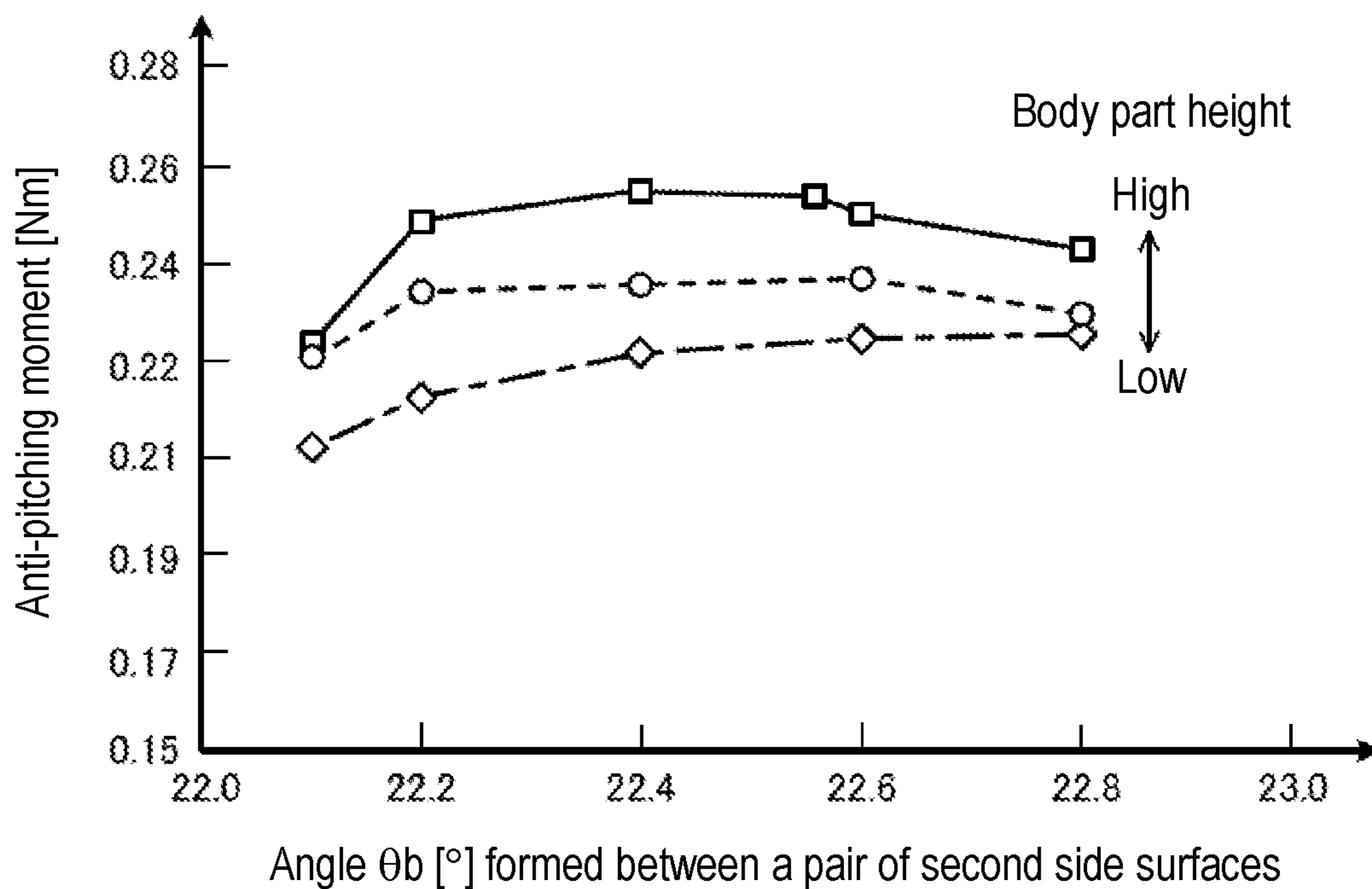


FIG. 6

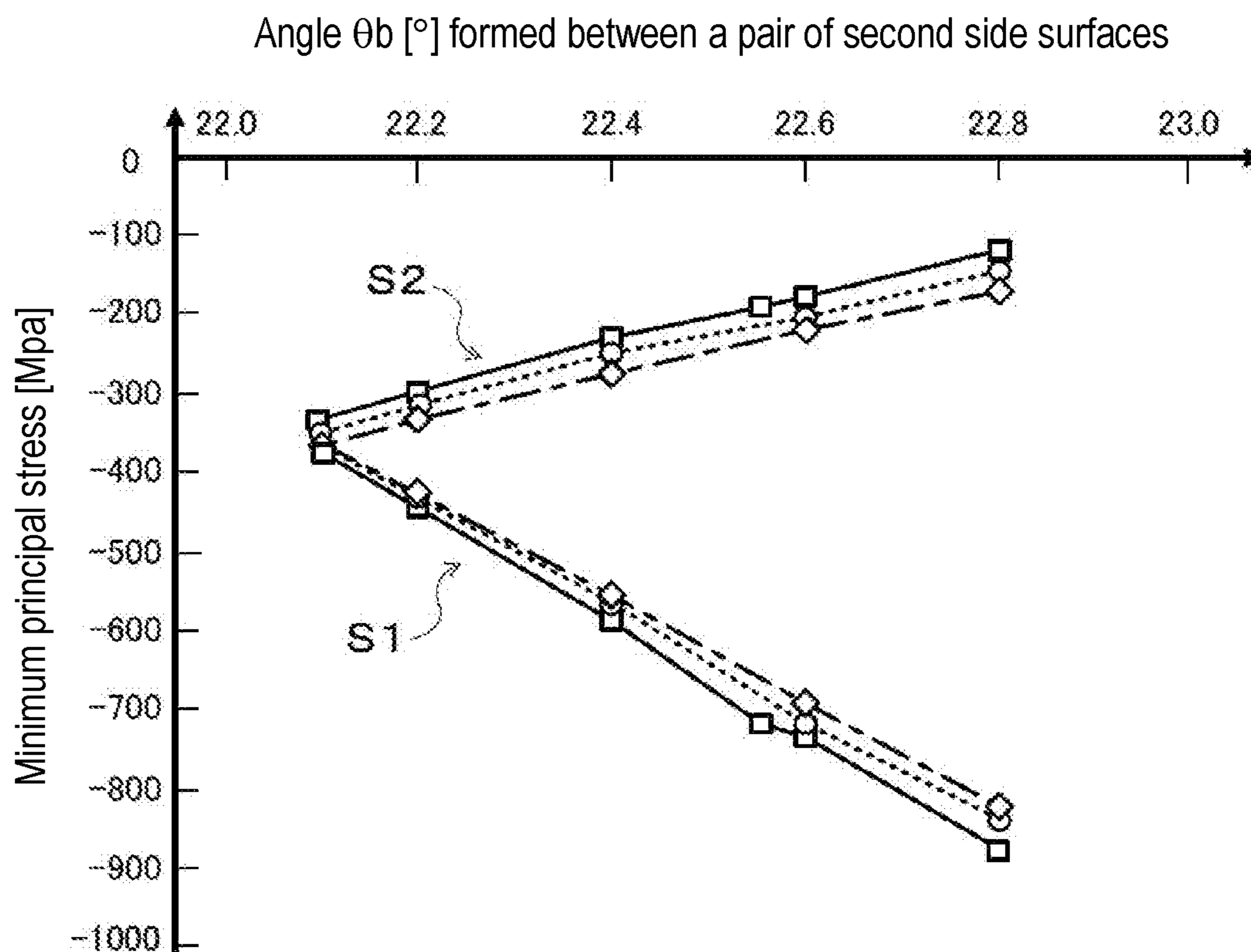


FIG. 7

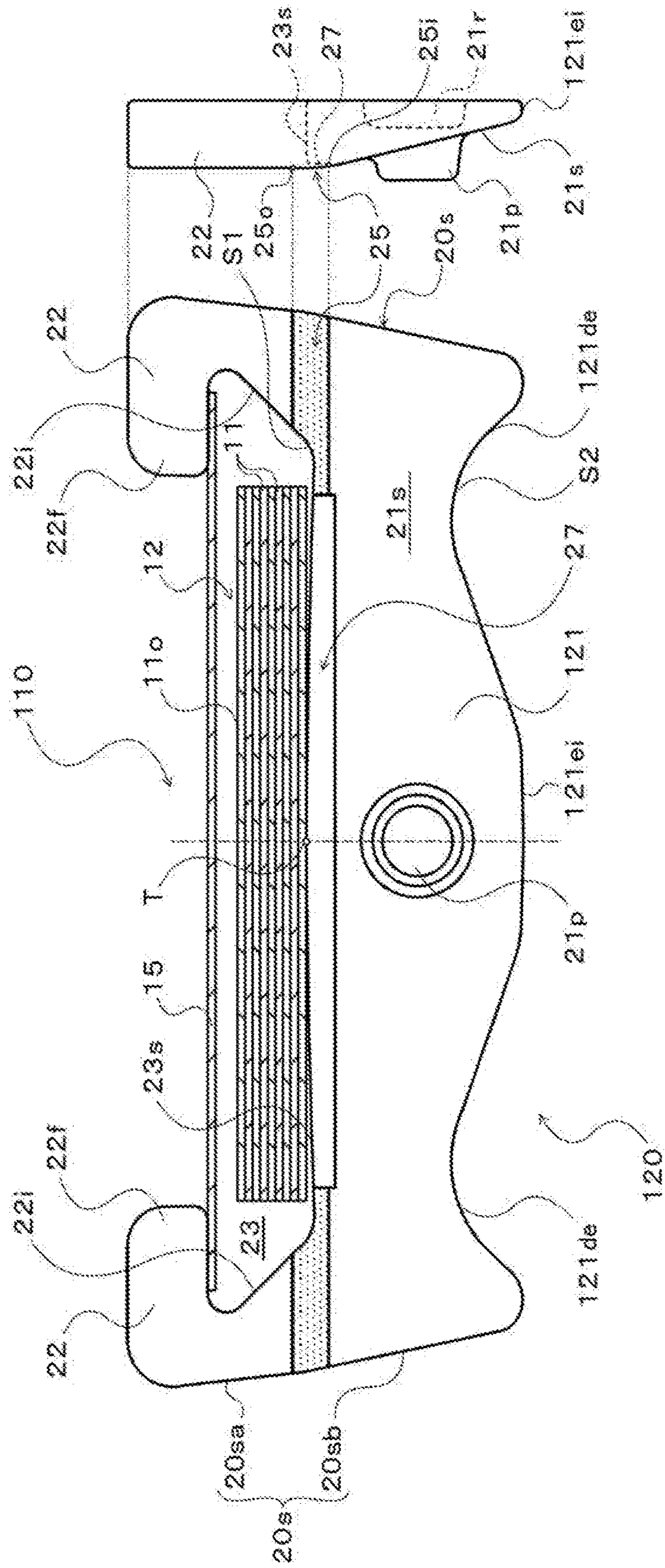




FIG. 8

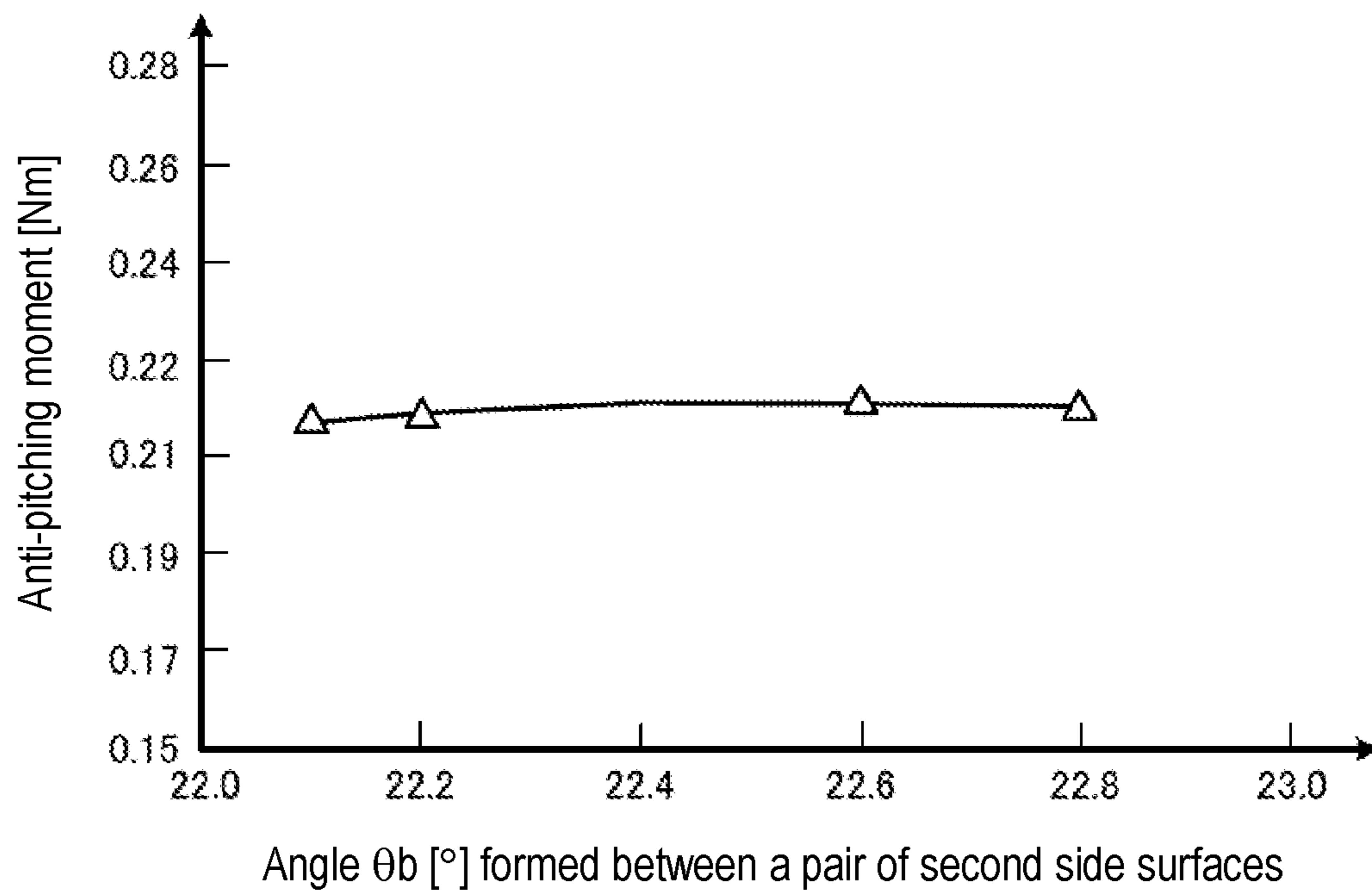


FIG. 9

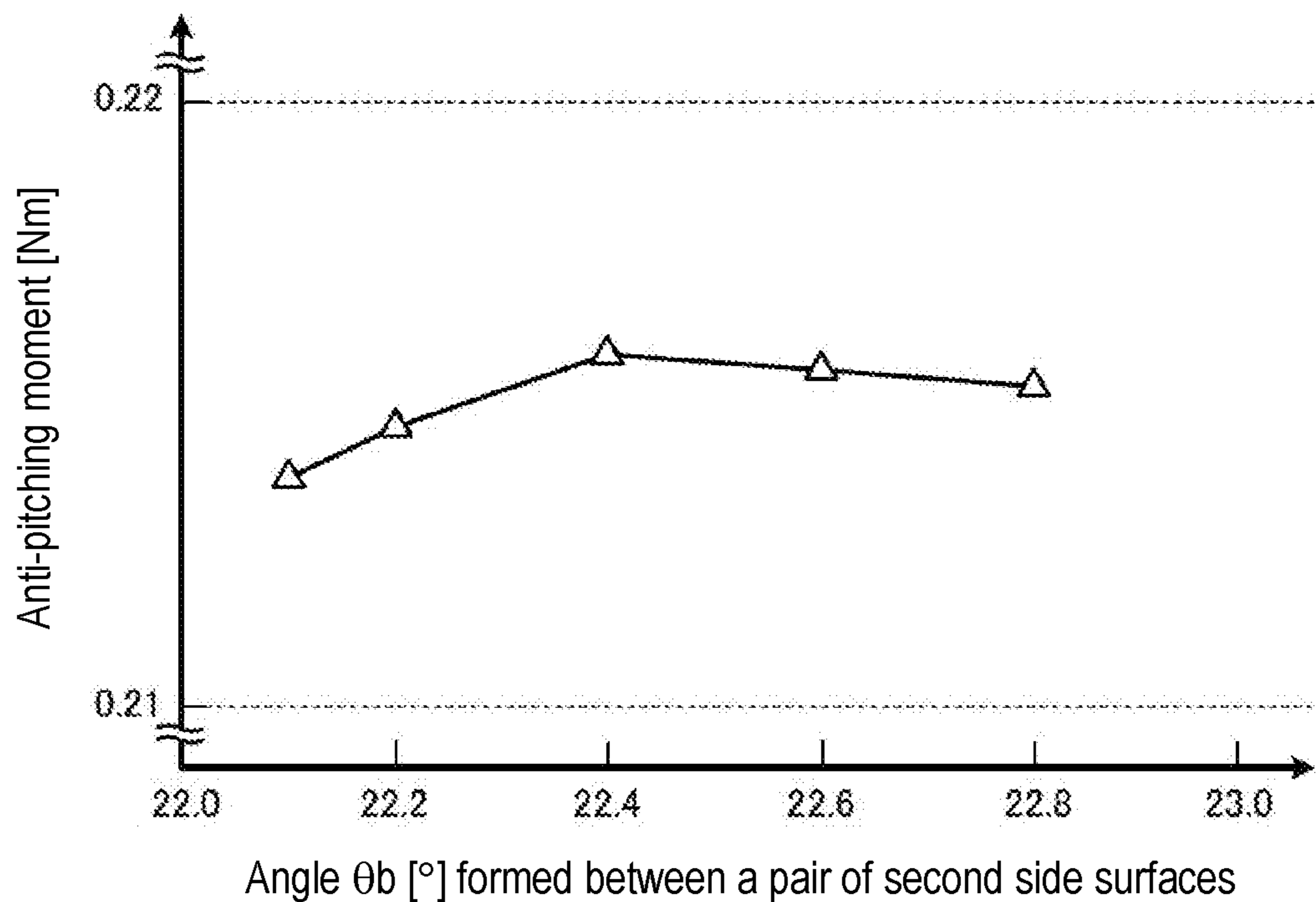


FIG. 10

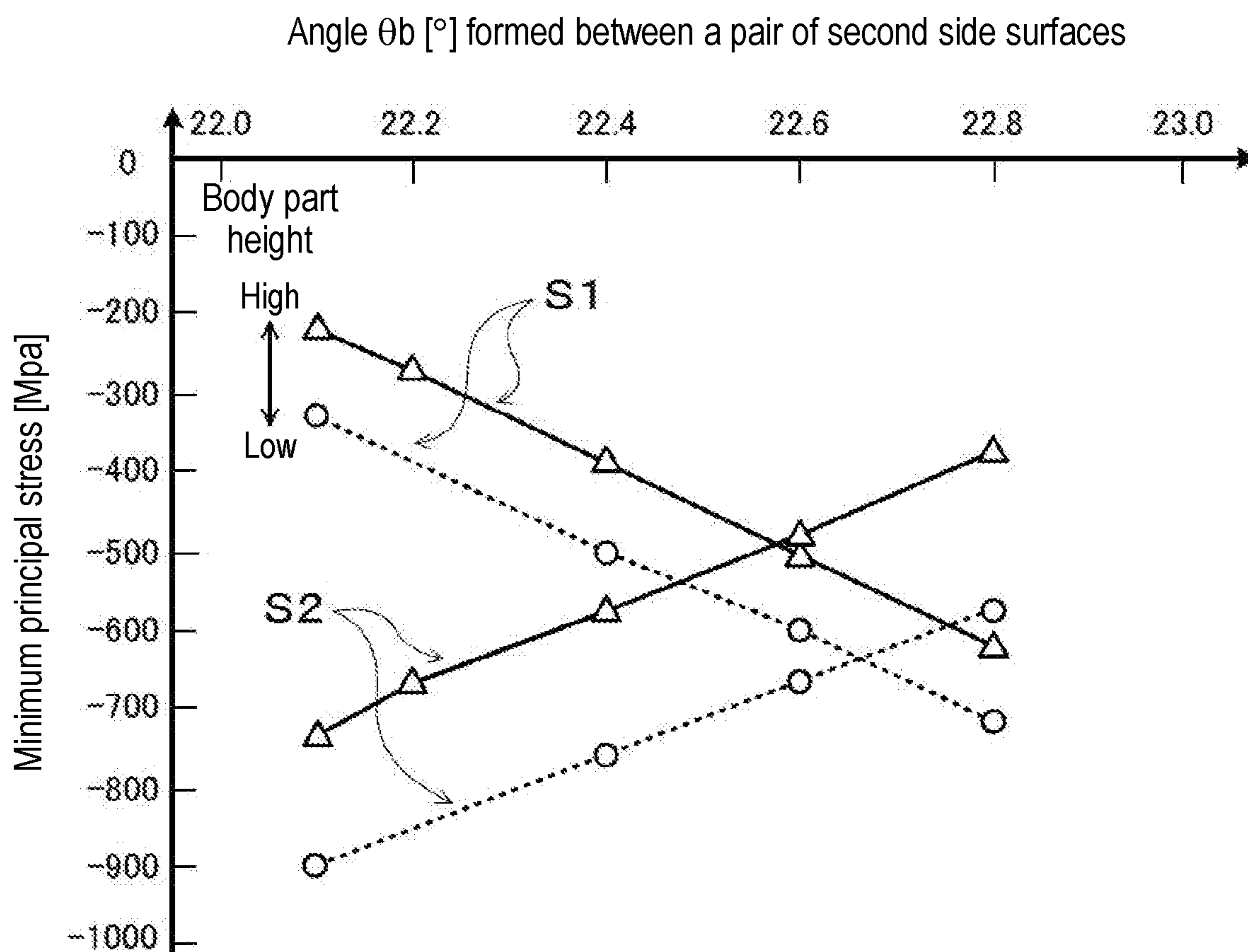


FIG. 11

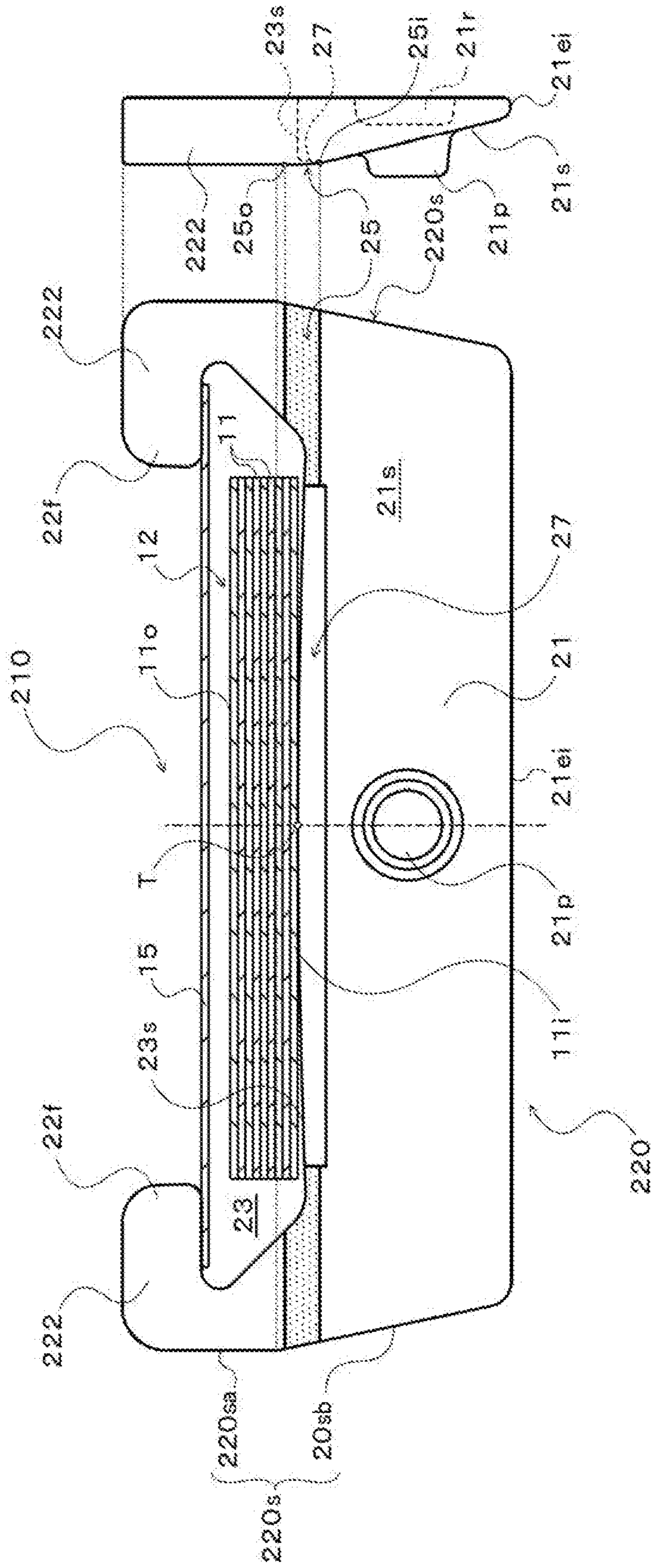


FIG. 12

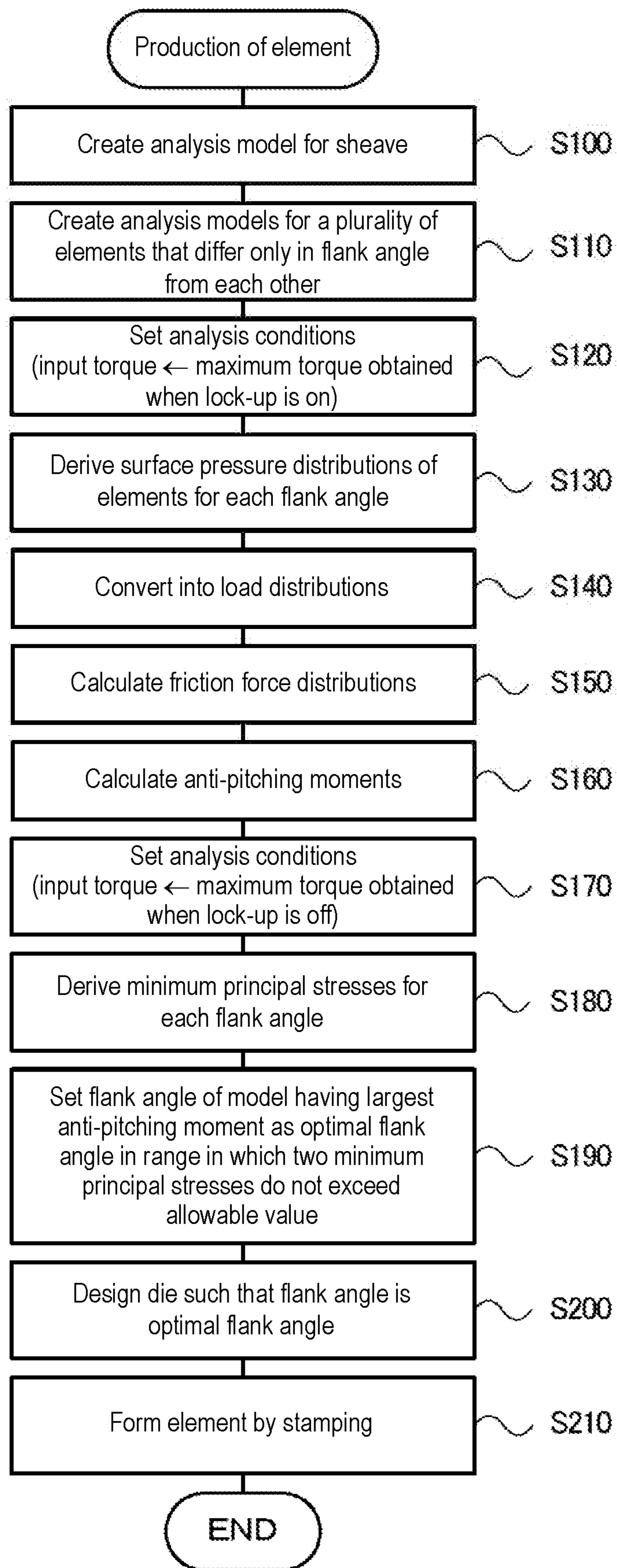


FIG. 13

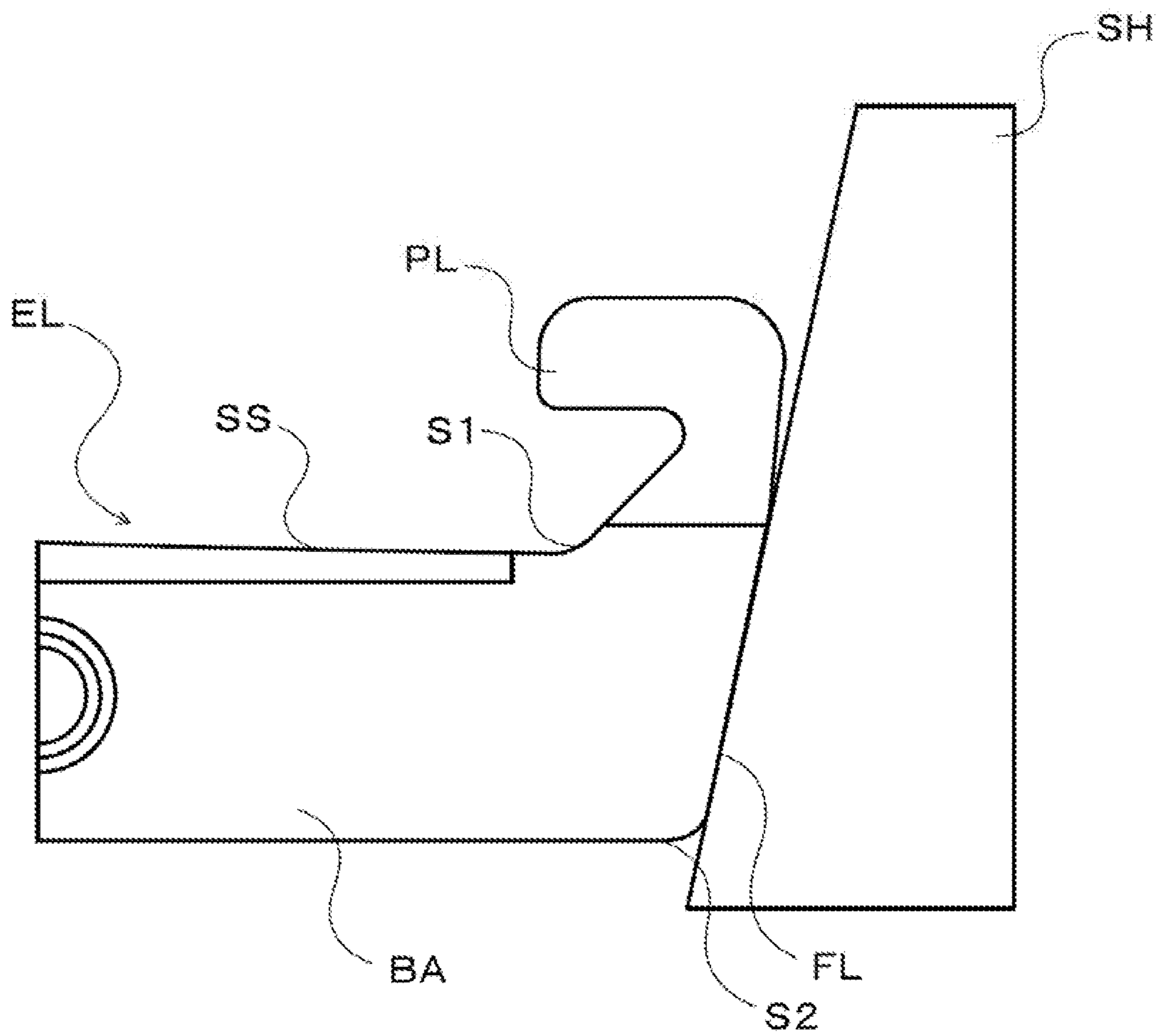


FIG. 14

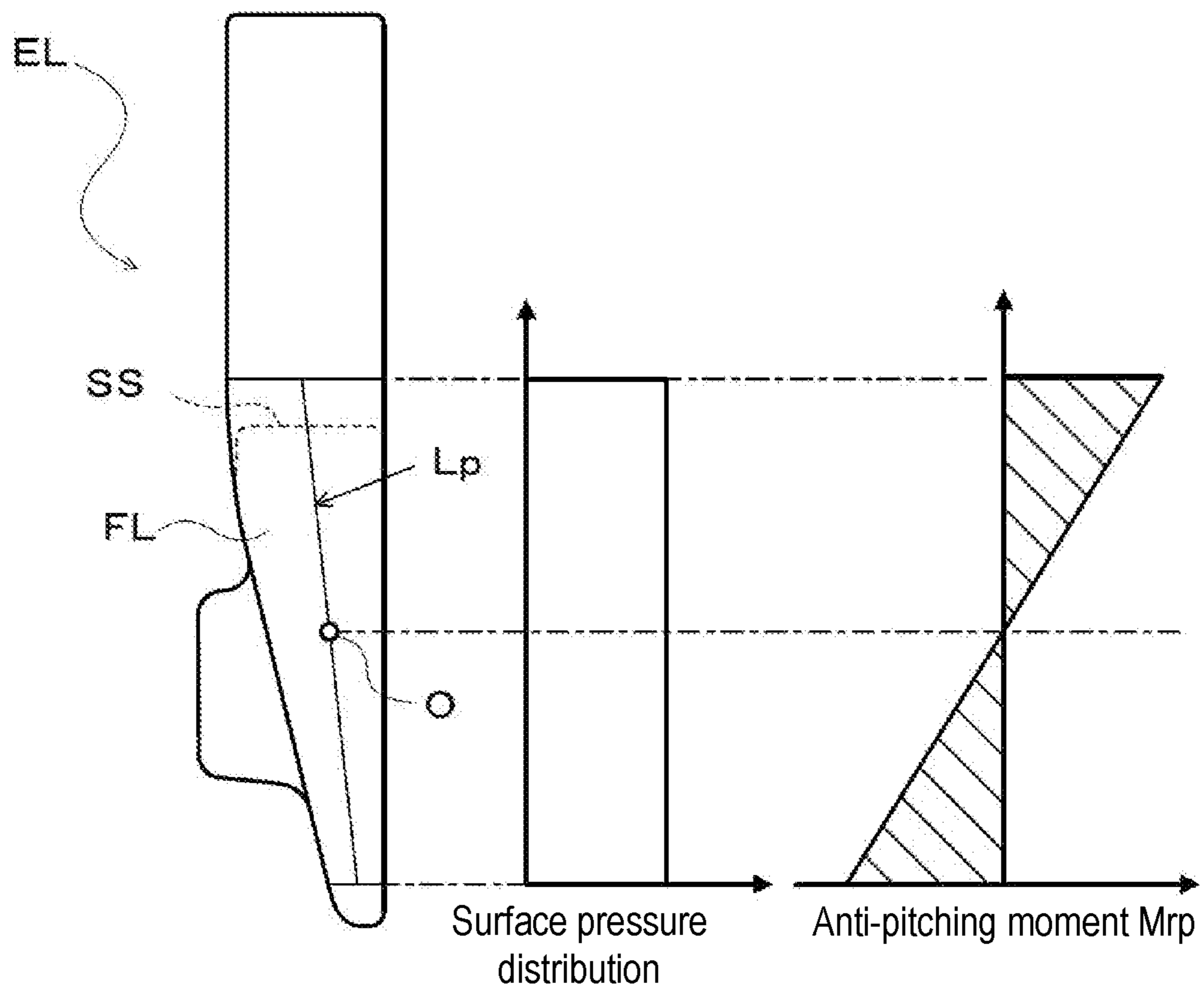


FIG. 15

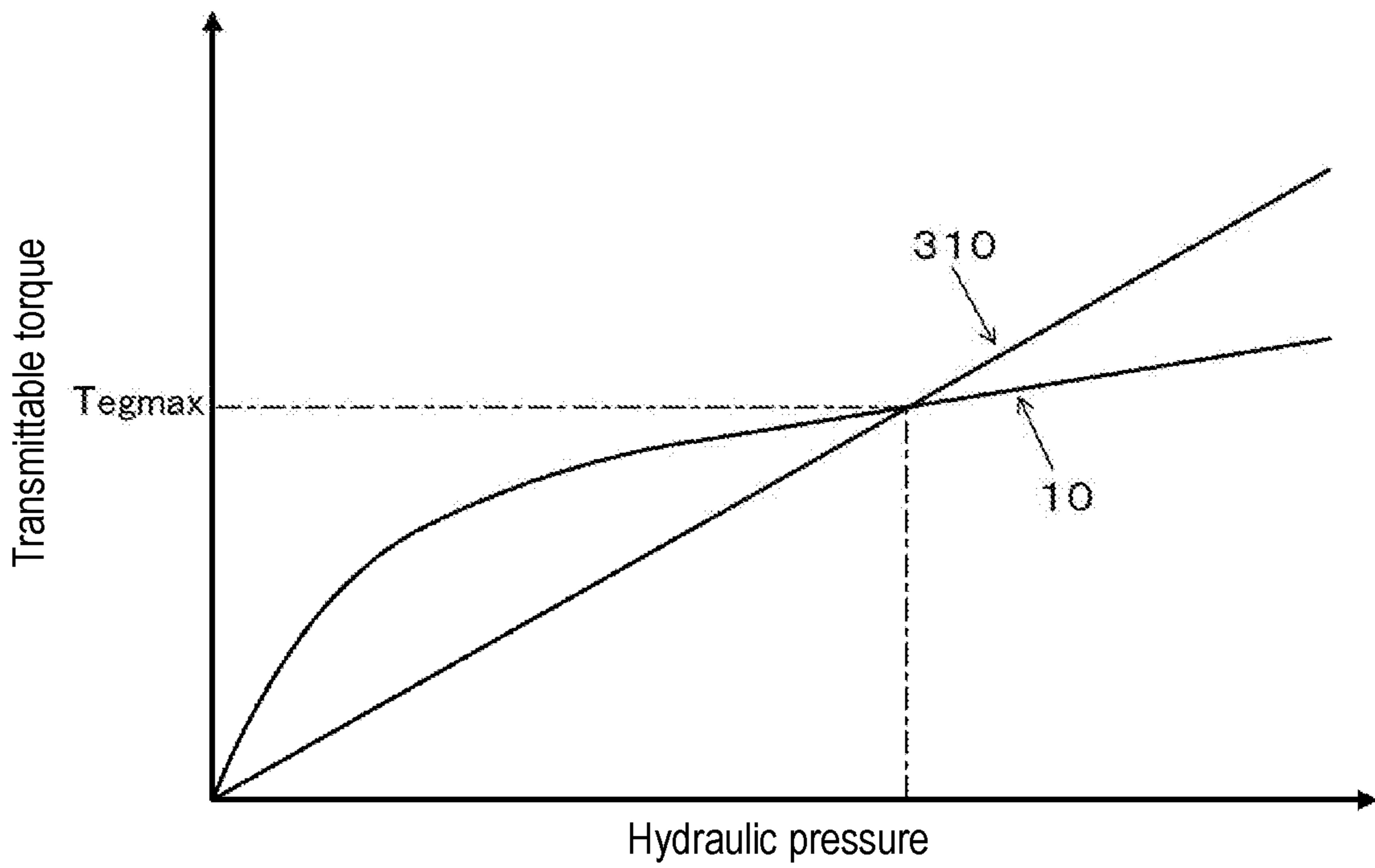


FIG. 16

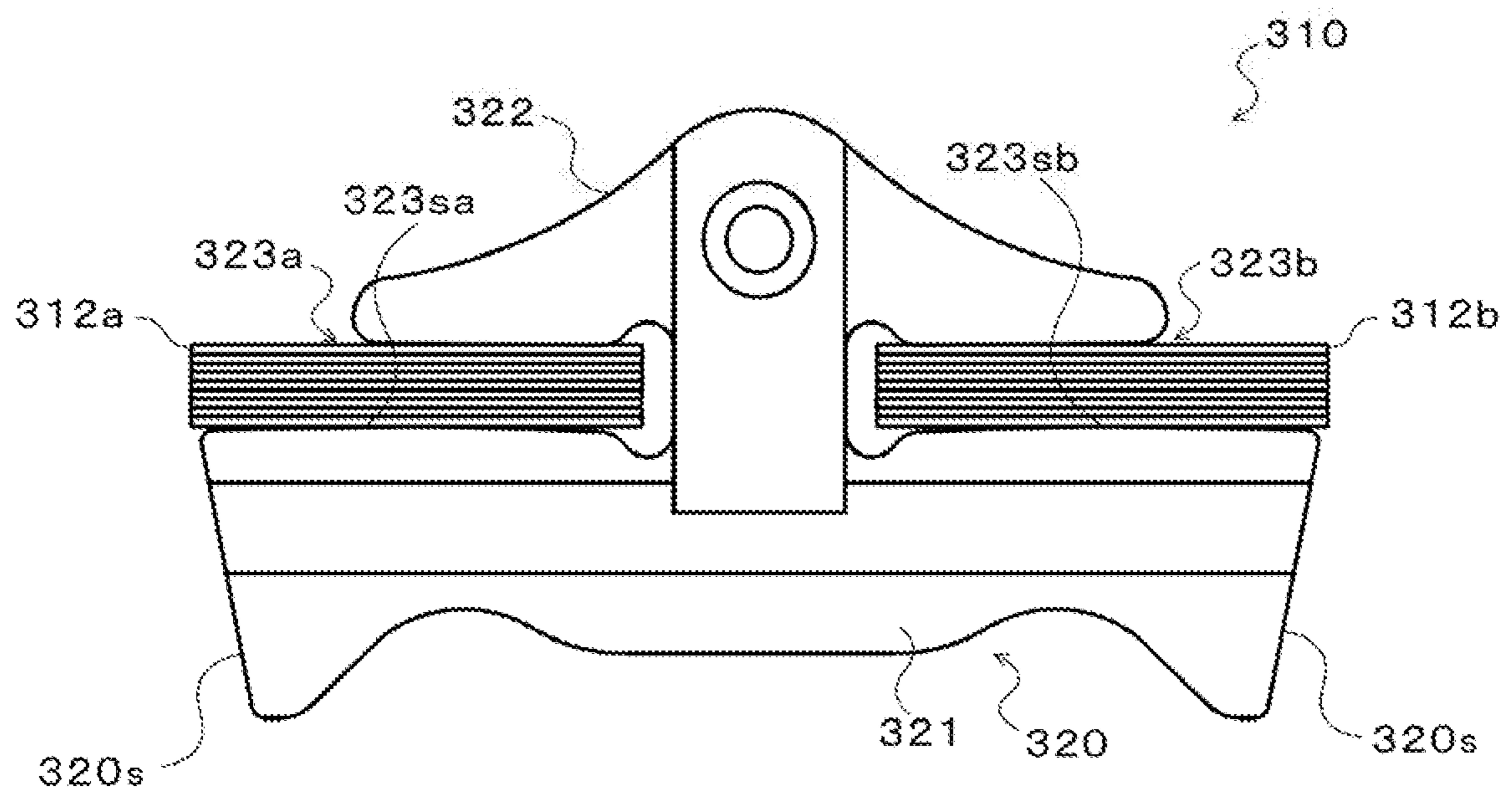




FIG. 17

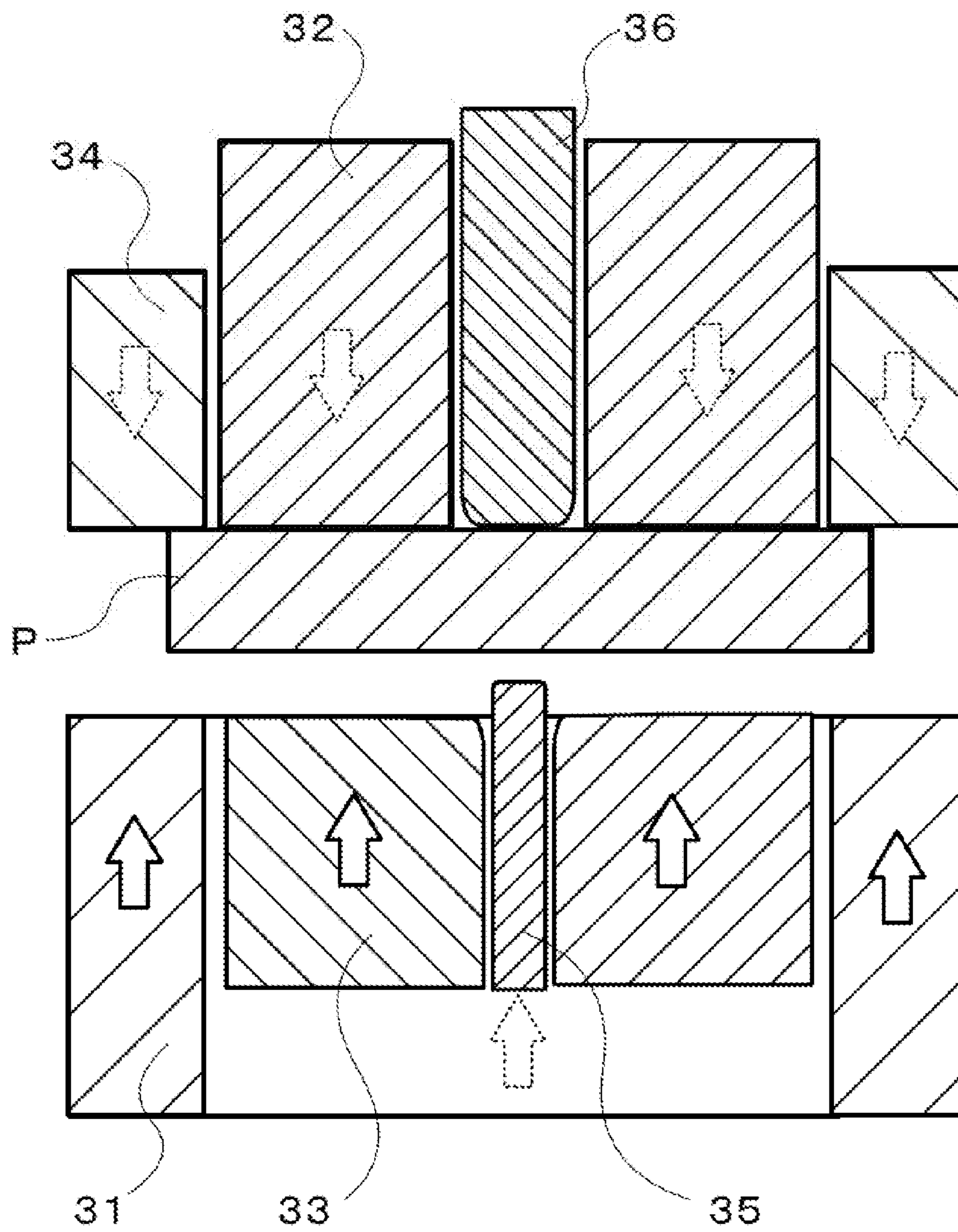


FIG. 18

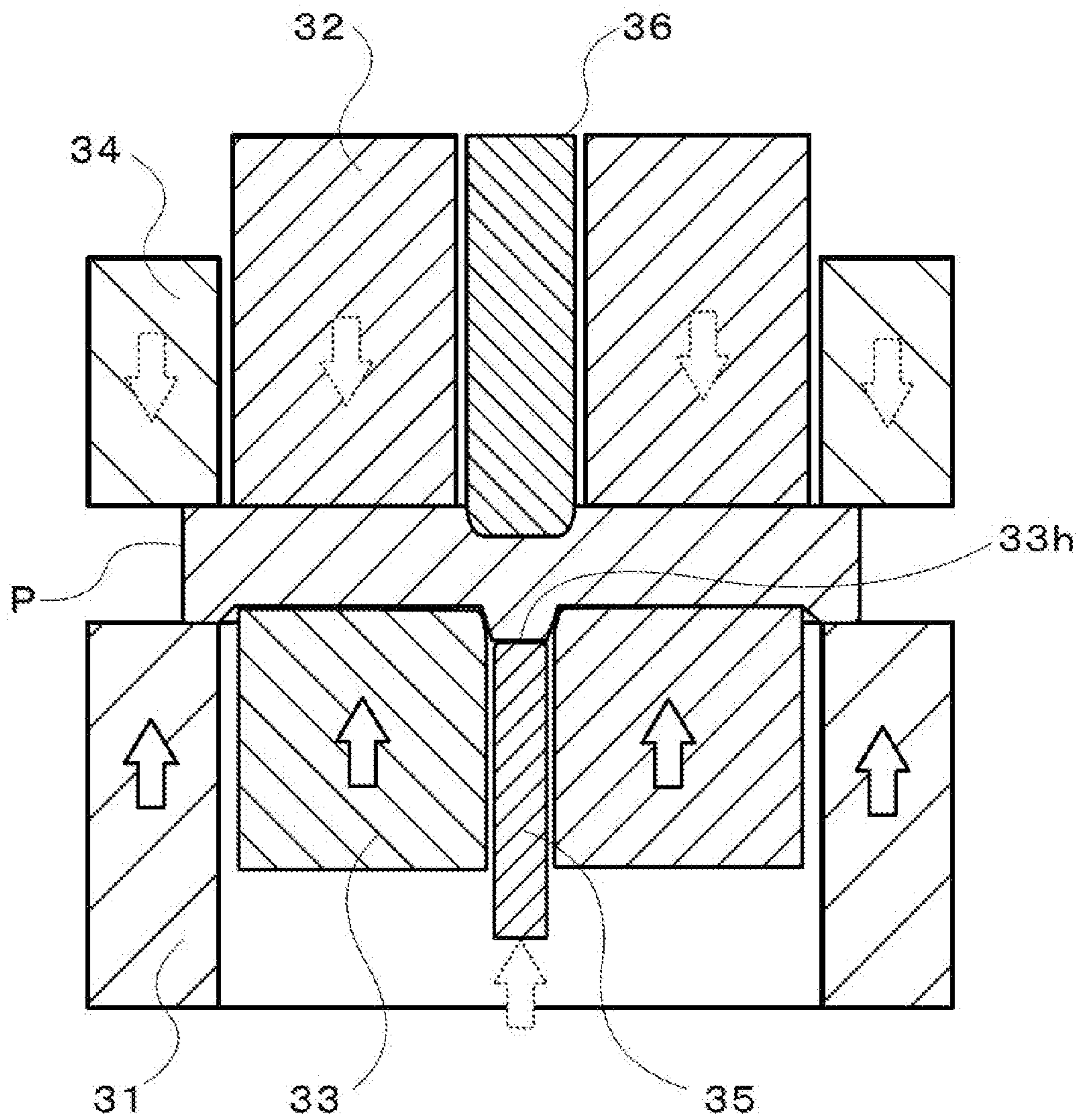
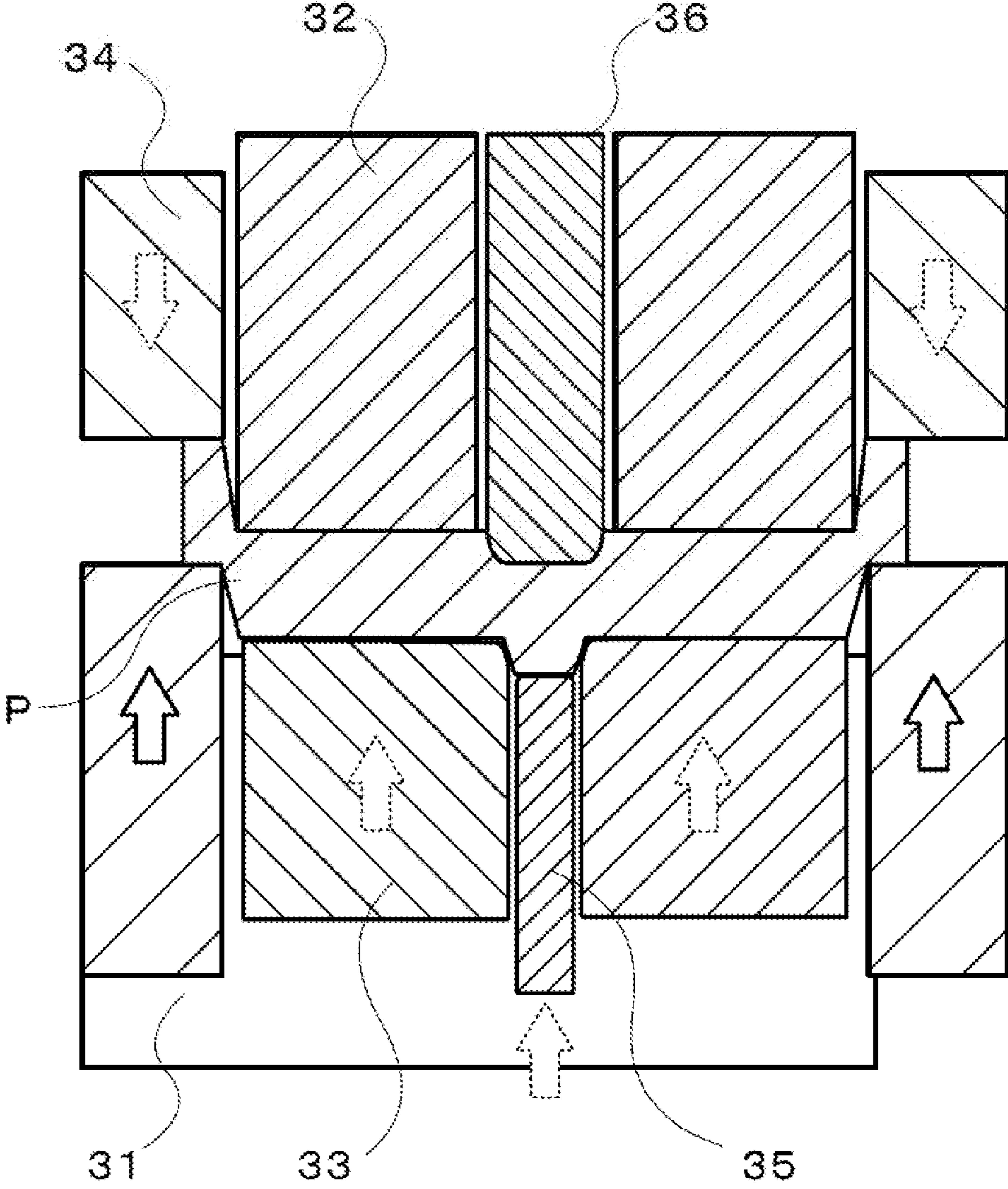


FIG. 19



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**TRANSMISSION BELT AND  
CONTINUOUSLY VARIABLE  
TRANSMISSION, METHOD FOR  
DESIGNING ELEMENT, AND METHOD FOR  
PRODUCING ELEMENT**

CROSS REFERENCE TO RELATED  
APPLICATIONS

This application is a National Stage of International Application No. PCT/JP2018/045014 filed Dec. 7, 2018 claiming priority based on Japanese Patent Application No. 2017-235552, filed Dec. 7, 2017, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The present specification discloses a transmission belt, a continuously variable transmission, a method for designing an element, and a method for producing an element.

BACKGROUND ART

Conventionally, as a transmission belt of this kind, there is proposed a transmission belt that includes a plurality of elements each including a main body part (body part) including a saddle surface, and column parts (pillar parts) extending from both sides in a width direction of the saddle surface in the width direction; and a ring that circularly puts together the plurality of elements by an inner circumferential surface of the ring coming into contact with each of the saddle surfaces of the plurality of elements (see, for example, Patent Literature 1). A pair of side surfaces of the body part is formed so as to be spaced farther apart from each other as they extend from an inner circumference side to an outer circumference side of the ring.

In addition, there is also proposed a transmission belt that includes a plurality of transverse elements (elements) each including a substantially inverted-trapezoidal body part, a substantially triangular head part extending from a central portion in a width direction thereof toward outer circumference sides of rings, and a pair of depressed parts that open outward in the width direction between the body part and the head part; and carriers (rings) including two sets of continuous bands and held in the pair of depressed parts (see, for example, Patent Literature 2). A pair of lateral side surfaces of each transverse element is tapered inward in a radial direction, and is formed such that an angle formed between the pair of lateral side surfaces is larger than an opening angle of V-shaped grooves of pulleys. By this, contact pressure between the lateral side surfaces of the transverse element and the pulley is prevented from decreasing outward in the radial direction, enabling to reduce local wear of the lateral side surfaces.

Patent Literature 1: JP 2017-180784 A

Patent Literature 2: JP 2003-535289 A

SUMMARY OF THE DISCLOSURE

In the transmission belt described in Patent Literature 1 that includes elements each including a body part including a saddle surface that comes into contact with a ring; and a pair of pillar parts extending from both sides in a width direction of the saddle surface in the width direction, the element is pushed out from an inner circumference side to an outer circumference side of the ring by a compression force received by a pair of side surfaces of the element from a

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pulley, by which a force (tension) from the ring acts on a central portion in the width direction of the saddle surface from the outer circumference side to the inner circumference side of the ring. Due to this, the element is significantly deformed by the force received by the central portion in the width direction of the saddle surface from the ring. As a result, a bias occurs in contact pressure (surface pressure) between the pair of side surfaces and the pulley, causing local wear of the pair of side surfaces.

In the transmission belt described in Patent Literature 2 that includes elements each including a body part; a substantially triangular head part; and a pair of depressed parts that open outward in a width direction between the body part and the head part, the occurrence of deformation in sheaves is taken into account upon determining an opening angle of a pair of side surfaces of the element. The element of this configuration is also likely to be deformed by a force (tension) received from rings as described above, but the deformation of the element by the force received from the rings is not considered at all.

The present disclosure reduces local wear of a pair of side surfaces of an element that come into contact with a V-shaped groove of a pulley, the element having, between the pair of side surfaces in a width direction of a body part, a saddle surface with which an inner circumferential surface of a ring comes into contact.

The present disclosure adopts the following aspects to reduce the local wear of a pair of side surfaces.

A transmission belt of the present disclosure is a transmission belt including: a plurality of elements; and a ring that circularly puts together the plurality of elements, the transmission belt being wound around V-shaped grooves of a pair of pulleys of a continuously variable transmission to transmit power, and the main points are that the elements each include a body part including a saddle surface that comes into contact with the ring; a pair of pillar parts extending from both sides in a width direction of the saddle surface in the width direction; and a pair of side surfaces, the pair of side surfaces each include a first side surface formed on a corresponding one of the pillar parts; and a second side surface formed so as to continue from the first side surface, and located more on an inner circumference side of the ring than the first side surface, a pair of the first side surfaces each are formed so as to be inclined toward an inner side of a corresponding one of the pillar parts with respect to an extending direction, from an inner circumference side to an outer circumference side of the ring, of a corresponding one of the second side surfaces continuing from the first side surface, and a pair of the second side surfaces is formed such that the second side surfaces are spaced farther apart from each other as the second side surfaces extend from the inner circumference side to the outer circumference side of the ring, and that an angle formed between the pair of the second side surfaces is larger by 0.2 to 0.8 degrees than an opening angle of the V-shaped grooves of the pulleys.

In an element having a pair of pillar parts on both sides in a width direction of a saddle surface with which a ring comes into contact, upon torque transmission, a force (compression force) from a pulley acts on a pair of side surfaces and a force (tension) from the ring acts on a central portion in the width direction of the saddle surface from an outer circumference side to an inner circumference side of the ring. At this time, the element is significantly deformed by the force from the ring acting on the central portion in the width direction of the saddle surface toward the inner circumference side, and a bias occurs in contact pressure (surface pressure) between the pair of side surfaces and the

pulley. As a result, the pair of side surfaces swings (itches) in a front-back direction when receiving a force in a tangential direction from the pulley, causing local wear in each side surface of the element. The inventors of the present application have found by study that by forming an element such that a pair of first side surfaces each are inclined toward an inner side of a pillar part with respect to an extending direction, from an inner circumference side to an outer circumference side of a ring, of a second side surface continuing from the first side surface, a pair of second side surfaces is spaced farther apart from each other as they extend from the inner circumference side to the outer circumference side of the ring, and an angle formed between the pair of second side surfaces is larger by 0.2 to 0.8 degrees than an opening angle of the V-shaped grooves of the pulleys, upon torque transmission, the pair of second side surfaces becomes substantially parallel to contact surfaces (inclined surfaces) of the pulley with the element being deformed, and a bias in contact pressure between the pair of side surfaces and the pulley occurring when the pair of side surfaces (second side surfaces) receives a force in a tangential direction from the pulley is reduced. By this, a resistance force (anti-pitching moment) by friction between the element and the pulley can be increased, and pitching of the element is excellently suppressed, enabling to reduce local wear of the pair of side surfaces that come into contact with the V-shaped groove of the pulley.

A continuously variable transmission of the present disclosure is a continuously variable transmission including: a pair of pulleys; and a transmission belt including a plurality of elements and a ring that circularly puts together the plurality of elements, the transmission belt being wound around V-shaped grooves of the pair of pulleys, and the main points are that the elements each include a body part including a saddle surface that comes into contact with the ring; a pair of pillar parts extending from both sides in a width direction of the saddle surface in the width direction; and a pair of side surfaces, the pair of side surfaces each include a first side surface formed on a corresponding one of the pillar parts; and a second side surface formed so as to continue from the first side surface, and located more on an inner circumference side of the ring than the first side surface, a pair of the first side surfaces each are formed so as to be inclined toward an inner side of a corresponding one of the pillar parts with respect to an extending direction, from an inner circumference side to an outer circumference side of the ring, of a corresponding one of the second side surfaces continuing from the first side surface, and a pair of the second side surfaces is formed such that the second side surfaces are spaced farther apart from each other as the second side surfaces extend from the inner circumference side to the outer circumference side of the ring, and that an angle formed between the pair of second side surfaces is larger by 0.2 to 0.8 degrees than an opening angle of the V-shaped grooves of the pulleys.

The continuously variable transmission of the present disclosure includes the above-described transmission belt of the present disclosure. Hence, the continuously variable transmission of the present disclosure can provide the same advantageous effect as the transmission belt of the present disclosure, i.e., an advantageous effect of being able to reduce local wear of a pair of side surfaces that come into contact with the V-shaped groove of the pulley.

A method for designing an element of the present disclosure is a method for designing a plurality of elements of a transmission belt that includes the plurality of elements each including a body part, a pair of side surfaces located at both

edges in a width direction of the body part, and a saddle surface located between the pair of side surfaces in the width direction; and a ring that circularly puts together the plurality of elements by an inner circumferential surface of the ring coming into contact with each of the saddle surfaces of the plurality of elements, and that is wound around V-shaped grooves of a pair of pulleys of a continuously variable transmission to transmit power, and the main points are that a pulleys' specification including an opening angle of the pulleys, an elements' specification including flank angles, each being an angle formed between the pair of side surfaces, and an analysis condition including input torque of the continuously variable transmission are set, and by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, distributions of friction forces in a radial direction of the ring exerted between the pair of side surfaces and the pulleys are derived for a plurality of different flank angles, rotational moments at a center of pitching of the elements are derived for the plurality of flank angles from friction force distributions derived for the plurality of flank angles, and a flank angle suitable for the continuously variable transmission is determined based on the rotational moments derived for the plurality of flank angles.

In the method for designing an element of the present disclosure, a pulleys' specification including an opening angle of the pulleys, an elements' specification including flank angles, each being an angle formed between a pair of side surfaces, and an analysis condition including input torque of the continuously variable transmission are set, and by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, friction force distributions (distributions of friction forces in a ring radial direction) between the pair of side surfaces and the pulleys are derived for a plurality of different flank angles, rotational moments at the center of pitching of the elements are derived for the plurality of flank angles from the derived friction force distributions, and a flank angle suitable for the continuously variable transmission is determined based on the derived rotational moments. The rotational moment at the center of pitching of the element corresponds to a resistance force by a friction force exerted when the element receives a force from the pulley, and thus, by determining a flank angle based on the rotational moment, pitching of the element can be excellently suppressed, enabling to reduce local wear of the pair of side surfaces that come into contact with the V-shaped groove of the pulley.

A method for producing an element of the present disclosure is a method for producing a plurality of elements of a transmission belt that includes the plurality of elements each including a body part, a pair of side surfaces located at both edges in a width direction of the body part, and a saddle surface located between the pair of side surfaces in the width direction; and a ring that circularly puts together the plurality of elements by an inner circumferential surface of the ring coming into contact with each of the saddle surfaces of the plurality of elements, and that is wound around V-shaped grooves of a pair of pulleys of a continuously variable transmission to transmit power, and the main points are that a pulleys' specification including an opening angle of the pulleys, an elements' specification including flank angles, each being an angle formed between the pair of side surfaces, and an analysis condition including input torque of the continuously variable transmission are set, and by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, distributions of friction forces in a radial direction of the ring exerted between the

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pair of side surfaces and the pulleys are derived for a plurality of different flank angles, rotational moments at a center of pitching of the elements are derived for the plurality of flank angles from friction force distributions derived for the plurality of flank angles, a flank angle suitable for the continuously variable transmission is determined based on the rotational moments derived for the plurality of flank angles, a die is formed based on the determined flank angle, and outside shapes of the elements are formed by performing press working using the formed die.

The method for producing an element of the present disclosure includes the above-described method for designing an element. Hence, the method for producing an element of the present disclosure can provide the same advantageous effect as the method for designing an element of the present disclosure, i.e., an advantageous effect of being able to reduce local wear of a pair of side surfaces that come into contact with the V-shaped groove of the pulley.

## BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic configuration diagram of a continuously variable transmission 1 of the present embodiment.

FIG. 2 is a partial cross-sectional view of a transmission belt 10 included in the continuously variable transmission 1.

FIG. 3 is an enlarged view of an element 20 included in the transmission belt 10.

FIG. 4 is a partial cross-sectional view of the transmission belt 10.

FIG. 5 is an illustrative diagram showing a relationship between the body part height of the element 20, an angle  $\theta_b$  formed between a pair of second side surfaces 20sb, and anti-pitching moment.

FIG. 6 is an illustrative diagram showing a relationship between the body part height of the element 20, the angle  $\theta_b$  formed between the pair of second side surfaces 20sb, and minimum principal stresses.

FIG. 7 is a partial cross-sectional view of a transmission belt 110 of another embodiment.

FIG. 8 is an illustrative diagram showing a relationship between the body part height of an element 120 included in the transmission belt 110, an angle  $\theta_b$  formed between a pair of second side surfaces 20sb, and anti-pitching moment.

FIG. 9 is an enlarged view in which a scale interval of the anti-pitching moment in FIG. 8 is enlarged.

FIG. 10 is an illustrative diagram showing a relationship between the body part height of the element 120, the angle  $\theta_b$  formed between the pair of second side surfaces 20sb, and minimum principal stresses.

FIG. 11 is a partial cross-sectional view of a transmission belt 210 of another embodiment.

FIG. 12 is an illustrative diagram showing a procedure of production of the element 20.

FIG. 13 is an illustrative diagram showing an example of analysis models for a sheave (pulley) and an element.

FIG. 14 is an illustrative diagram showing a relationship between a distribution of surface pressure received by a second side surface 20sb of an element 20 from a pulley and anti-pitching moment.

FIG. 15 is an illustrative diagram showing a relationship between transmittable torque and hydraulic pressure for the transmission belt 10 of the present embodiment and a transmission belt 310 of a comparative example.

FIG. 16 is a partial cross-sectional view of the transmission belt 310 of the comparative example.

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FIG. 17 is an illustrative diagram showing a state of formation of an element 20.

FIG. 18 is an illustrative diagram showing a state of formation of the element 20.

FIG. 19 is an illustrative diagram showing a state of formation of the element 20.

## DESCRIPTION OF EMBODIMENTS

Next, modes for carrying out various aspects of the present disclosure will be described with reference to the drawings.

FIG. 1 is a schematic configuration diagram of a continuously variable transmission 1 of the present embodiment. The continuously variable transmission 1 is mounted on a vehicle and includes, as shown in the drawing, a primary shaft 2 serving as a driving-side rotating shaft; a primary pulley 3 provided on the primary shaft 2; a secondary shaft 4 serving as a driven-side rotating shaft and disposed parallel to the primary shaft 2; a secondary pulley 5 provided on the secondary shaft 4; and a transmission belt 10 wound around a pulley groove (V-shaped groove) of the primary pulley 3 and a pulley groove (V-shaped groove) of the secondary pulley 5.

The primary shaft 2 is coupled through a forward/reverse switching mechanism (not shown) to an input shaft (not shown) coupled to a power source such as an engine (internal combustion engine). The primary pulley 3 includes a fixed sheave 3a which is formed integrally with the primary shaft 2; and a moving sheave 3b which is axially and slidably supported on the primary shaft 2 through a ball spline, etc. In addition, the secondary pulley 5 includes a fixed sheave 5a which is formed integrally with the secondary shaft 4; and a moving sheave 5b which is axially and slidably supported on the secondary shaft 4 through a ball spline, etc., and which is axially biased by a return spring 8.

Furthermore, the continuously variable transmission 1 includes a primary cylinder 6 which is a hydraulic actuator for changing the groove width of the primary pulley 3; and a secondary cylinder 7 which is a hydraulic actuator for changing the groove width of the secondary pulley 5. The primary cylinder 6 is formed behind the moving sheave 3b of the primary pulley 3, and the secondary cylinder 7 is formed behind the moving sheave 5b of the secondary pulley 5. Hydraulic oil is supplied to the primary cylinder 6 and the secondary cylinder 7 from a hydraulic control device (not shown) in order to change the groove widths of the primary pulley 3 and the secondary pulley 5, by which the speed of torque transmitted to the primary shaft 2 from the engine, etc., through the input shaft and the forward/reverse switching mechanism is steplessly changed, and the torque can be outputted to the secondary shaft 4. The torque outputted to the secondary shaft 4 is transmitted to drive wheels of the vehicle through a gear mechanism, a differential gear, and a drive shaft (none of which are shown).

FIG. 2 is a partial cross-sectional view of the transmission belt 10. As shown in the drawing, the transmission belt 10 includes a single layered ring 12 formed by layering a plurality of (e.g., nine in the present embodiment) endless ring materials 11 in a thickness direction (ring diameter direction); a single endless retainer ring 15; and a plurality of (e.g., several hundred in total) elements 20 which are circularly arranged (put together) along an inner circumferential surface of the layered ring 12.

The plurality of ring materials 11 forming the layered ring 12 each are an elastically deformable material cut out of a drum made of steel sheet, and are processed so as to have

roughly the same thickness and have different circumference lengths which are predetermined for the respective ring materials **11**. The retainer ring **15** is, for example, an elastically deformable ring cut out of a drum made of steel sheet, and is processed so as to have roughly the same thickness as or a thinner thickness than the ring materials **11** and have a longer inner circumference length than an outer circumference length of a ring material **11** that is the outermost layer of the layered ring **12**. By this, in a state in which the layered ring **12** and the retainer ring **15** are concentrically disposed (a no load state in which tension does not act), as shown in FIG. 2, a circular clearance is created between an outer circumferential surface of the ring material **11** that is the outermost layer and an inner circumferential surface of the retainer ring **15**.

Each element **20** is, for example, stamped out from a steel sheet by press working. As shown in FIG. 2, the element **20** includes a body part **21** extending horizontally in the drawing; a pair of pillar parts **22** extending from both edge parts of the body part **21** in the same direction; and a single ring holding part (depressed part) **23** defined between the pair of pillar parts **22** so as to open on free end sides of the respective pillar parts **22**.

An edge **21<sub>ei</sub>** of the body part **21** which is on an inner side (inner circumference side) in a radial direction of the layered ring **12** is formed in flat shape in a width direction.

The pair of pillar parts **22** extends outward in the radial direction of the layered ring **12** (in a direction going from the inner circumference side to the outer circumference side of the transmission belt **10** (layered ring **12**), i.e., upward in the drawing) from both sides in the width direction of a saddle surface **23<sub>s</sub>** which is the bottom of the ring holding part **23**, and a hook part **22<sub>f</sub>** that protrudes in the width direction of the saddle surface **23<sub>s</sub>** is formed at a free end part of each pillar part **22**. The pair of hook parts **22<sub>f</sub>** extends so as to face each other with a spacing therebetween that is slightly longer than the width of the layered ring **12** (ring materials **11**) and is shorter than the width of the retainer ring **15**.

As shown in FIG. 2, the layered ring **12** is disposed in the ring holding part **23**, and the saddle surface **23<sub>s</sub>** of the ring holding part **23** comes into contact with the inner circumferential surface of the layered ring **12**, i.e., an inner circumferential surface of a ring material **11** that is the innermost layer. The saddle surface **23<sub>s</sub>** is formed in left-right symmetrical convex curved surface shape (crowning shape) that is gently inclined downward in the drawing as the saddle surface **23<sub>s</sub>** extends outward in the width direction, with a central portion thereof in the width direction being a top portion T. By this, a centripetal force directed toward the top portion T is given to the layered ring **12** by friction with the saddle surface **23<sub>s</sub>**, enabling to center the layered ring **12**. Note, however, that the saddle surface **23<sub>s</sub>** may include a plurality of convex curved surfaces in the width direction that are curved outward in the radial direction of the layered ring **12**.

In addition, the elastically deformed retainer ring **15** is allowed to fit into the ring holding part **23** from a portion between the pair of hook parts **22<sub>f</sub>** of the element **20**. The retainer ring **15** is disposed between the outer circumferential surface of the ring material **11** that is the outermost layer of the layered ring **12** and the hook parts **22<sub>f</sub>** of the element **20**, enclosing the layered ring **12**, and restricts, together with the pair of pillar parts **22**, the element **20** from falling off the layered ring **12** or the layered ring **12** from falling off the element **20**. By this, the plurality of elements **20** are circularly put together (arranged) along the inner circumferential surface of the layered ring **12**. In the present embodiment, a

single or a plurality of openings (slots) which are not shown are made in the retainer ring **15**, by which the retainer ring **15** is easily elastically deformed, enabling to secure attachability to the elements **20**.

On the front (one surface) of the element **20** there are formed, as shown in FIG. 2, a pair of locking edge parts (contact areas) **25**, a non-contact part **27**, a tapered surface (inclined surface) **21<sub>s</sub>**, and a single protrusion (dimple) **21<sub>p</sub>**. The pair of locking edge parts **25** is formed on the front of the element **20** with a spacing therebetween in the width direction of the saddle surface **23<sub>s</sub>** so as to be placed across their corresponding pillar parts **22** and the body part **21**. In addition, the non-contact part **27** is formed between the pair of locking edge parts **25** in the above-described width direction. Furthermore, the tapered surface **21<sub>s</sub>** is formed on the front (one surface) of the body part **21** so as to extend from the non-contact part **27** and the pair of locking edge parts **25** to an opposite side to a protruding direction of each pillar part **22**, i.e., a belt's inner circumference side (a lower side in FIG. 2). The protrusion **21<sub>p</sub>** protrudes from the tapered surface **21<sub>s</sub>** at a central portion in a width direction of the front of the body part **21**.

In addition, as shown in FIG. 2, a portion of the front of the element **20** (mainly, the front of the pillar parts **22**) and a portion of the back (the other surface) of the element **20** that are located more on a belt's outer circumference side than each locking edge part **25** and the non-contact part **27** are formed to be flat. By this, each pillar part **22** of the element **20** has a certain thickness. In addition, as shown in FIG. 2, the tapered surface **21<sub>s</sub>** which is located more on the belt's inner circumference side (the lower side in FIG. 2) than each locking edge part **25** and the non-contact part **27** gets closer to the back (back side) as the tapered surface **21<sub>s</sub>** is distanced from the pillar parts **22** (as the tapered surface **21<sub>s</sub>** extends toward the belt's inner circumference side). Furthermore, a recessed part **21<sub>r</sub>** is formed on the back of the element **20** (the body part **21**) so as to be located on a back side of the protrusion **21<sub>p</sub>**. When the transmission belt **10** is assembled, a protrusion **21<sub>p</sub>** of an adjacent element **20** loosely fits into the recessed part **21<sub>r</sub>**.

Each locking edge part **25** has a short, belt-shaped convex curved surface. In the present embodiment, each locking edge part **25** has a cylindrical surface (curved surface) having a predetermined radius of curvature. Each locking edge part **25** includes a pivot (line of contact) about which the element **20** and an adjacent element **20** rotate by coming into contact with each other, and the location of the pivot changes between an outer circumference side edge part **25<sub>o</sub>** of the locking edge part **25** (a boundary line between the front of the pillar part **22** and the locking edge part **25**) and an inner circumference side edge part **25<sub>i</sub>** of the locking edge part **25** (a boundary line between the tapered surface **21<sub>s</sub>** and the locking edge part **25**), according to a transmission gear ratio  $\gamma$  of the continuously variable transmission **1**.

In addition, the non-contact part **27** is a belt-shaped depressed part formed on the front (one surface) of the body part **21** so as to open at the saddle surface **23<sub>s</sub>** in a state in which the element **20** and an adjacent element **20** are in contact with each other, and to extend in the width direction along the saddle surface **23<sub>s</sub>** to cut off the pair of locking edge parts **25**. The bottom of the non-contact part **27** is a flat surface parallel to the front (mainly, the front of the pillar parts **22**) and back of the element **20**, and is recessed more on the back side than a surface of each locking edge part **25**. By this, the thickness of the saddle surface **23<sub>s</sub>** becomes smaller than the thickness of the pillar parts **22**. In addition, corner parts of the non-contact part **27** (depressed part) and

an edge part of the body part **21** that defines the non-contact part **27** are given an R shape by chamfering, etc.

By forming such a non-contact part **27** in the element **20**, in the transmission belt **10**, it becomes possible to excellently suppress contact between the element **20** and an adjacent element **20** at portions other than the locking edge parts **25**. As a result, deformation of the adjacent element **20** is suppressed which is caused by application of a load from the central portion in the width direction of the element **20** on which a large moment acts to the adjacent element **20**, enabling to further improve the durability of the elements **20**.

In addition, the element **20** has a pair of side surfaces **20s** formed so as to be spaced farther apart from each other as they extend from the inner circumference side to the outer circumference side of the layered ring **12** (the outer side in the radial direction of the layered ring **12**). As shown in FIGS. **2** and **3**, each side surface **20s** has a first side surface **20sa** located on a pillar part **22** side, i.e., on an opposite side (outer side) to an inner surface **22i** of the pillar part **22**; and a second side surface **20sb** formed so as to continue from the first side surface **20sa**, and located more on the inner side in the radial direction of the layered ring **12** than the first side surface **20sa**. In the present embodiment, a pair of the first side surfaces **20sa** is formed so as to be spaced farther apart from each other as they extend toward the outer side in the radial direction of the layered ring **12** as with the second side surfaces **20sb**, and is formed such that, as shown in FIG. **3**, an angle  $\theta_{ab}$  formed between the first side surface **20sa** and the second side surface **20sb** is less than 180 degrees at a boundary (B) between the first side surface **20sa** and the second side surface **20sb**, i.e., the first side surface **20sa** is inclined toward the inner side of the pillar part **22** with respect to an extending direction, from the inner circumference side to the outer circumference side of the layered ring **12**, of the second side surface **20sb**. By this, the strength of each pillar part **22** can be excellently secured.

Furthermore, an angle  $\theta_b$  (flank angle) formed between a pair of the second side surfaces **20sb** is, as shown in FIG. **4**, larger than an opening angle  $\theta_O$  of the pulley grooves of the primary pulley **3** and the secondary pulley **5**. In the present embodiment, the angle  $\theta_b$  is determined to be larger by 0.2 to 0.8 degrees than the opening angle  $\theta_O$ . On the other hand, an angle  $\theta_a$  formed between a pair of the first side surfaces **20sa** is determined to be smaller than the opening angle  $\theta_O$  of the pulley grooves. By this, the second side surfaces **20sb** of the element **20** come into frictional contact with the surfaces of the pulley groove of the primary pulley **3** or the pulley groove of the secondary pulley **5**, and thereby receive a compression force from the pulley **3** or **5**, and become torque transmission surfaces (flank surfaces) that transmit torque from the primary pulley **3** to the secondary pulley **5** by a friction force in a tangential direction of the pulleys **3** and **5**. On the other hand, when torque is transmitted from the primary pulley **3** to the secondary pulley **5** by the transmission belt **10**, a pair of the first side surfaces **20sa** basically does not come into contact with the surfaces of the pulley groove. In addition, as shown in FIG. **3**, the boundary B between the first side surface **20sa** and the second side surface **20sb** is located more on the belt's outer circumference side than the outer circumference side edge part **25o** of the locking edge part **25** when the element **20** is viewed in plan view.

When torque is transmitted from the primary pulley **3** to the secondary pulley **5** by the transmission belt **10** such as that described above, while the second side surfaces **20sb** of the side surfaces **20s** of each element **20** abut on the surfaces

of the pulley groove, the first side surfaces **20sa** on the pillar part **22** side can be prevented from coming into contact with the surfaces of the pulley groove. By this, upon torque transmission from the primary pulley **3** to the secondary pulley **5**, a force (compression force) can be prevented from being directly applied to the first side surfaces **20sa**, i.e., the pillar parts **22**, of each element **20** from the primary pulley **3** or the secondary pulley **5**, enabling to suppress deformation of the pillar parts **22**.

In addition, since the angle  $\theta_b$  formed between a pair of the second side surfaces **20sb** abutting on the surfaces of the pulley groove is larger than the opening angle  $\theta_O$  of the pulley grooves, when a compression force acting on a pair of the second side surfaces **20sb** from the pulley **3** or **5** is small (relatively small torque is transmitted), torque is transmitted such that only the outer side in the radial direction of the layered ring **12** comes into contact with the surfaces (inclined surfaces) of the pulley groove. When the compression force acting on a pair of the second side surfaces **20sb** increases (torque to be transmitted increases), by the compression force and a force (tension) acting on the saddle surface **23s** from the layered ring **12** from the outer side to the inner side in the radial direction of the layered ring **12**, as shown in FIG. **3**, a bending moment  $M_1$  that tries to fold the pair of pillar parts **22** inward in the width direction of the element **20** and a moment  $M_2$  that tries to bend both sides in the width direction of the edge **21ei** (an edge part of the body part **21** on the belt's inner circumference side) which is on the opposite side to the saddle surface **23d** of the body part **21**, toward the belt's outer circumference side occur in each element **20**. By this, the element **20** is deformed, and the angle  $\theta_b$  formed between a pair of the second side surfaces **20sb** decreases due to the deformation of the element **20**, and matches the opening angle  $\theta_O$  of the pulley grooves in the end. Namely, a pair of the second side surfaces **20sb** becomes substantially parallel to the surfaces (inclined surfaces) of the pulley groove, and comes into surface contact with the surfaces of the pulley groove, transmitting torque. Then, when the compression force acting on a pair of the second side surfaces **20sb** further increases (torque to be transmitted further increases), a force that tries to deform the element **20** further increases, and although the angle  $\theta_b$  formed between a pair of the second side surfaces **20sb** is substantially equal to the opening angle  $\theta_O$  of the pulley grooves and thus does not change, inner side surfaces, in the radial direction of the layered ring **12**, of the element **20** are more strongly pressed against the pulley. Namely, a pair of the second side surfaces **20sb** transmits torque, with the inner sides in the radial direction of the layered ring **12** being in strong contact with the surfaces of the pulley groove. In this case, a bias occurs in contact pressure (surface pressure) between a pair of the second side surfaces **20sb** and the pulley **3** or **5**, and due to the bias in the contact pressure of a pair of the second side surfaces **20sb**, pitching which is a swing in a front-back direction (a swing about a pivot which is the location of the center of a load received by the second side surfaces **20sb**) occurs in the element **20**, by which local wear occurs in a pair of the second side surfaces **20sb**.

The inventors of the present application have fabricated a plurality of elements **20** having different angles  $\theta_b$  formed between a pair of second side surfaces **20sb** (22.1 degrees, 22.2 degrees, 22.4 degrees, 22.6 degrees, and 22.8 degrees), and have analyzed a distribution of contact pressure acting on the pair of second side surfaces **20sb** of each element **20** along with torque transmission, calculated normal forces at each location in the belt radial direction on the pair of second



side surfaces **20sb** based on results of the analysis, and thereby derived resistance forces (anti-pitching moments) by friction which are exerted when a force in a tangential direction from an adjacent element **20** (mainly, a force (push-out force) inputted from the adjacent element **20** 5 through the locking edge parts **25**) is received. Note that the primary pulley **3** and the secondary pulley **5** that have an opening angle  $\theta O$  of 22.0 degrees have been used. FIG. **5** is an illustrative diagram showing a relationship between the body part height of the element **20**, the angle  $\theta b$  formed 10 between the pair of second side surfaces **20sb**, and anti-pitching moment. Note that in FIG. **5** anti-pitching moments are derived for each of the plurality of elements **20** having different angles  $\theta b$  formed between a pair of second side surfaces **20sb** and having different heights of a body part **21** 15 (lengths in the belt radial direction), and pieces of derived data for the same body part height are connected by a straight line. A solid line in the drawing represents derived data of anti-pitching moments obtained by using elements **20** with the highest body part height, a dash-dotted line in the drawing represents derived data of anti-pitching moments obtained by using elements **20** with the lowest body part height, and a dashed line in the drawing represents derived data of anti-pitching moments obtained by using elements **20** with an intermediate body part height. As shown in the drawing, it has been found that regardless of the body part height, elements **20** whose angles  $\theta b$  (flank angles) formed between the pair of second side surfaces **20sb** are larger by 0.2 to 0.8 degrees (particularly, 0.2 to 0.6 degrees) than the opening angle  $\theta O$  (22.0 degrees) of the pulley grooves have high anti-pitching moments. By this, upon torque transmission, by allowing the pair of second side surfaces **20sb** to become substantially parallel to the surfaces of the pulley groove, when each element **20** is deformed to some extent by the above-described bending moments **M1** and **M2** (when a compression force from the pulley **3** or **5** exerted on the element **20** is greater than or equal to a predetermined value), a bias in contact pressure of the pair of second side surfaces **20sb** against the pulley **3** or **5** can be reduced, enabling to excellently suppress local wear of the second side surfaces **20sb**. In addition, in the present embodiment, since the edge **21ei** on the inner circumference side of the body part **21** is formed in flat shape in the width direction, in addition to high stiffness of the element **20**, by increasing the body part height, the stiffness of the element **20** can be further increased. By this, deformation of the element **20** is suppressed, and thus, the anti-pitching moment increases, enabling to excellently suppress pitching of the element **20**.

Furthermore, the boundary **B** between the first side surface **20sa** and the second side surface **20sb** is located more on the outer side (outer circumference side) in the belt radial direction than the outer circumference side edge part **25o** of the locking edge part **25** of the element **20**. By this, the second side surfaces **20sb** (flank surfaces) extend toward the outer circumference side and the contact area of the second side surfaces **20sb** with the pulley **3** or **5** increases, and thus, the anti-pitching moment can be increased and pitching of the element **20** can be excellently suppressed. Note, however, that the boundary **B** between the first side surface **20sa** and the second side surface **20sb** may be formed between the outer circumference side edge part **25o** and the inner circumference side edge part **25i** of the locking edge part **25**, or may be formed on an inner side (inner circumference side) in the belt radial direction than the inner circumference side edge part **25i** of the locking edge part **25**.

In addition, as shown in FIG. **3**, the outer circumference side edge part **25o** of the locking edge part **25** is located

more on an outer circumference side than a straight line **L0** passing through the top portion **T** of the saddle surface **23s** (convex curved surface) and extending in the width direction, and the inner circumference side edge part **25i** is located more on an inner circumference side than the above-described straight line **L0**. By this, the locking edge parts **25** are compressed by the pulley **3** or **5** through the second side surfaces **20sb**, enabling to improve torque transmission efficiency.

In addition, the inventors of the present application have further analyzed a minimum principal stress acting on a portion **S1** between the saddle surface **23s** and the inner surface **22i** of the pillar part **22**, and a minimum principal stress acting on an edge part **S2** (or a slightly inner side than the edge part **S2**) in the width direction of the edge **21ei** of the body part **21**. FIG. **6** is an illustrative diagram showing a relationship between the body part height of the element **20**, the angle  $\theta b$  formed between a pair of second side surfaces **20sb**, and minimum principal stresses. Note that in the drawing three lines on the bottom (downward sloping) represent derived data of minimum principal stresses acting on the portion **51** between the saddle surface **23s** and the inner surface **22i** of the pillar part **22**, and three lines on the top (upward sloping) represent derived data of minimum principal stresses acting on the edge part **S2** in the width direction of the edge **21ei** of the body part **21**. Note also that solid lines in the drawing each are a straight line that connects pieces of derived data for the same body part height which are the same as those represented by the solid line in FIG. **5**, dash-dotted lines in the drawing each are a straight line that connects pieces of derived data for the same body part height which are the same as those represented by the dash-dotted line in FIG. **5**, and dashed lines in the drawing each are a straight line that connects pieces of derived data for the same body part height which are the same as those represented by the dashed line in FIG. **5**. It indicates that as the value of a minimum principal stress acting on the portion **51** between the saddle surface **23s** and the inner surface **22i** of the pillar part **22** and the value of a minimum principal stress acting on the edge part **S2** (or a slightly inner side than the edge part **S2**) in the width direction of the edge **21ei** of the body part **21** get closer to each other, a minimum principal stress acting on the weakest portion (in the example of FIG. **6**, the minimum principal stress (the compression side is negative) acting on the portion **51** between the saddle surface **23s** and the inner surface **22i** of the pillar part **22**) can be reduced in absolute value, and shows that deformation of each element **20** upon torque transmission has been able to be excellently suppressed. As shown in the drawing, it has been found that the smaller the angle  $\theta b$  (flank angle) formed between the pair of second side surfaces **20sb**, i.e., the closer the angle  $\theta b$  is to the opening angle  $\theta O$  of the pulley **3** or **5**, a more excellent result is obtained. Therefore, by setting the angle  $\theta b$  (flank angle) formed between the pair of second side surfaces **20sb** to be larger by 0.2 to 0.8 degrees (more preferably, 0.2 to 0.6 degrees) than the opening angle  $\theta O$  of the pulley grooves of the primary pulley **3** and the secondary pulley **5**, deformation of each element **20** upon torque transmission can be excellently suppressed, enabling to excellently suppress local wear of the pair of second side surfaces **20sb**.

Although in the transmission belt **10** of the continuously variable transmission **1** of the embodiment, the edge **21ei** on the inner side (the inner circumference side) in the belt radial direction of the body part **21** is formed in flat shape in the width direction, two depressed parts **121de** that are depressed on a saddle surface **23s** side may be formed

between a central portion in a width direction of an edge **121ei** on an inner circumference side of a body part **121** and each of second side surfaces **20sb**, like an element **120** included in a transmission belt **110** of another embodiment shown in FIG. 7. The two depressed parts **121de** are defined by a combination of a concave cylindrical surface and a flat surface, and are formed such that, as shown in FIG. 7, the entire depressed part **121de** is closer to the second side surface **20sb** than to the central portion in the width direction of the element **120**. Note that the two depressed parts **121de** may be formed of only a curved surface. By this, without increasing the weight of the element **20**, the contact area of the second side surface **20sb** with the pulley **3** or **5** can be increased by extending the second side surfaces **20sb** (flank surfaces) toward the inner circumference side. As a result, the anti-pitching moment increases, enabling to excellently suppress pitching of the element **20**.

For the element **120** of a variant that has the two depressed parts **121de** on the edge **121ei** of the body part **121**, the inventors of the present application have fabricated a plurality of elements **120** having different angles  $\theta_b$  formed between a pair of second side surfaces **20sb** (22.1 degrees, 22.2 degrees, 22.4 degrees, 22.6 degrees, and 22.8 degrees), and have analyzed a distribution of contact pressure acting on the pair of second side surfaces **20sb** of each element **120** along with torque transmission, and thereby derived anti-pitching moments based on results of the analysis. Note that the pulleys **3** and **5** having an opening angle  $\theta_O$  of 22.0 degrees have been used. FIG. 8 is an illustrative diagram showing a relationship between the body part height of the element **120**, the angle  $\theta_b$  formed between the pair of second side surfaces **20sb**, and anti-pitching moment. In addition, FIG. 9 is an enlarged view in which a scale interval (0.21 Nm to 0.22 Nm) of the anti-pitching moment in FIG. 8 is enlarged. As shown in the drawing, it has been found that in the elements **120** of the variant, as with the elements **20** of the embodiment, elements **120** whose angles  $\theta_b$  (flank angles) formed between the pair of second side surfaces **20sb** are larger by 0.2 to 0.8 degrees (particularly, 0.2 to 0.6 degrees) than the opening angle  $\theta_O$  (22.0 degrees) of the pulley grooves have high anti-pitching moments. By this, upon torque transmission, even if each element **120** is deformed to some extent by the above-described bending moments **M1** and **M2**, a bias in contact pressure of the pair of second side surfaces **20sb** against the pulley **3** or **5** can be reduced, enabling to excellently suppress local wear of the second side surfaces **20sb**.

In addition, the inventors of the present application have further analyzed a minimum principal stress acting on the portion **51** between the saddle surface **23s** and the inner surface **22i** of the pillar part **22**, and a minimum principal stress acting on deepest parts **S2** of the two depressed parts **121de**. FIG. 10 is an illustrative diagram showing a relationship between the body part height of the element **120**, the angle  $\theta_b$  formed between a pair of second side surfaces **20sb**, and minimum principal stresses. Note that in the drawing two downward-sloping lines represent derived data of minimum principal stresses acting on the portion **51** between the saddle surface **23s** and the inner surface **22i** of the pillar part **22**, and two upward-sloping lines represent derived data of minimum principal stresses acting on the deepest parts **S2** of the depressed parts **121de**. Note also that solid lines in the drawing each are a straight line that connects pieces of derived data obtained by using elements **120** with a high body part height, and dashed lines in the drawing each are a straight line that connects pieces of derived data obtained by using elements **120** with a low

body part height. As shown in the drawing, it has been found that regardless of whether the body part height is high or low, when the angle  $\theta_b$  formed between the pair of second side surfaces **20sb** is 22.6 degrees, a minimum principal stress acting on the portion **51** between the saddle surface **23s** and the inner surface **22i** of the pillar part **22**, and a minimum principal stress acting on the deepest parts **S2** of the depressed parts **121de** get closest to each other, and the minimum principal stress acting on the weakest portion can be reduced in absolute value. Therefore, in the elements **120** of the variant, too, by setting the angle  $\theta_b$  (flank angle) formed between the pair of second side surfaces **20sb** to be larger by 0.2 to 0.8 degrees (more preferably, 0.2 to 0.6 degrees) than the opening angle  $\theta_O$  of the pulley groove of the primary pulley **3** or the secondary pulley **5**, deformation of each element **120** upon torque transmission can be excellently suppressed, enabling to excellently suppress local wear of the pair of second side surfaces **20sb**.

In the transmission belts **10** and **110** of the continuously variable transmissions **1** of the present embodiment and another embodiment, a pair of the first side surfaces **20sa** of the element **20** is formed such that, as with the second side surfaces **20sb**, the first side surfaces **20sa** are spaced farther apart from each other as they extend toward the outer side in the radial direction of the layered ring **12**, but the configuration is not limited thereto. Namely, like a transmission belt **210** of another embodiment shown in FIG. 11, of a pair of side surfaces **220s** of an element **220**, a pair of first side surfaces **220sa** formed on pillar parts **222** may be formed to be parallel to each other. In addition, the pair of first side surfaces may be formed so as to come closer to each other as they extend toward the outer side in the radial direction of the layered ring **12**.

In the transmission belts **10** and **110** of the continuously variable transmissions **1** of the present embodiment and another embodiment, a pair of the second side surfaces **20sb** of the element **20** is formed to be a flat surface, but the configuration is not limited thereto. For example, in a pair of the second side surfaces **20sb**, crank-shaped steps may be formed in the radial direction of the layered ring **12**.

In the transmission belts **10** and **110** of the continuously variable transmissions **1** of the present embodiment and another embodiment, a pair of hook parts **22f** is provided on each element **20** and the retainer ring **15** is disposed between the layered ring **12** and the hook parts **22f** of the plurality of elements **20**, but the configuration is not limited thereto. Namely, the hook parts **22f** may be omitted from each element **20** of the transmission belt **10**, and the retainer ring **15** may be omitted from the transmission belt **10**.

Now, a method for producing (method for designing) elements **20**, **120**, and **220** of the embodiment will be described using FIG. 12. The method for producing elements **20**, **120**, and **220** mainly includes an element design process (step **S100** to **S190**) in which an optimal flank angle  $\theta_b$  of the angle  $\theta_b$  (flank angle) formed between a pair of second side surfaces **20sb** of an element **20** is determined by stress analysis from the specifications of the elements **20**, **120**, and **220**, the specifications of the pulleys **3** and **5**, and analysis conditions; and an element forming process (step **S200** and **S210**) in which an element **20** is formed by stamping out a steel sheet such that the flank angle has the determined optimal flank angle  $\theta_b$ .

In the element design process, first, an analysis model for a sheave (pulley) is created (step **S100**) and analysis models for a plurality of elements that differ only in flank angle from each other are created (step **S110**). FIG. 13 is an illustrative diagram showing an example of analysis models for a

sheave (pulley) SH and an element EL. The analysis model for the sheave includes the outside and inside diameters of the sheave SH, the thickness of the sheave SH in a traveling direction of the element EL (a direction from back to front in FIG. 13), the angle of a contact surface (inclined surface) with the element EL, a material, etc. In addition, the analysis model for the element EL includes the shape, flank angle, material, etc., of the element EL. In the present embodiment, as shown in FIG. 13, the analysis model for the sheave (pulley) and the analysis model for the element are half models in which one side is omitted relative to a center line  $L_p$  passing through a central portion in a width direction of the element EL and extending in a radial direction of a ring, and stress analysis is performed using a single element EL. Subsequently, analysis conditions used when stress analysis is performed are set (step S120). Here, the setting of analysis conditions includes the setting of constraint conditions for the sheave SH and the element EL, the setting of a contact surface between the sheave SH and the element EL, the setting of load conditions of the element EL, etc. In the present embodiment, the setting of constraint conditions is performed such that the inside diameter of the sheave SH is constrained for all directions, a second side surface FL of the element EL is constrained in the traveling direction of the element EL, and the central portion in the width direction of the element EL is constrained in this width direction. The setting of a contact surface between the sheave SH and the element EL includes the setting of a range in a belt radial direction of a contact surface between the sheave SH and the element EL. The load conditions of the element EL are conditions related to a load received by a saddle surface SS of the element EL from the ring inward in a radial direction thereof. The setting of load conditions includes the setting of input torque inputted to the sheave SH (a sheave included in a primary pulley), and the setting of a transmission gear ratio. For the setting of input torque, in the present embodiment, a configuration is assumed in which a crankshaft of an engine is connected to a primary shaft (primary pulley) of a continuously variable transmission through a lock-up torque converter, and maximum torque that can be inputted to the primary shaft from the engine when lock-up is on (upon non-stalling) (torque obtained by multiplying engine's maximum torque by the amplification factor of the torque converter) is set. In addition, in the setting of a transmission gear ratio, in the present embodiment, a maximum reduction ratio that can be taken by the continuously variable transmission is set. Note that in the analysis conditions, hydraulic pressure from a hydraulic control device that is required to transmit torque set in the setting of torque from the sheave SH to the element EL is set with a safety factor of 1.0 (hydraulic pressure just appropriate to input torque).

Then, based on the analysis models for the sheave SH and the elements EL and the analysis conditions, stress analysis is performed for each of the plurality of elements EL having different flank angles, and distributions (surface pressure distributions) of contact pressure (surface pressure) received by the second side surface FL of each element EL at each location in a belt radial direction from the sheave SH are extracted (step S130). For the surface pressure distributions, in the present embodiment, as shown in FIG. 14, a surface pressure at a central portion in a plate thickness direction of the second side surface FL of the element EL (a surface pressure received at a location on the straight line  $L_p$  extending in the ring radial direction so as to pass through the central portion in the plate thickness direction) is extracted as a representative value. Of course, a surface pressure may be extracted at a plurality of locations in the

plate thickness direction. Subsequently, the extracted surface pressure distributions are converted into load distributions which are distributions of normal forces (loads) at each location in the belt radial direction on the second side surface FL of the element EL (step S140). The conversion from a surface pressure distribution into a load distribution can be performed by multiplying the plate thickness of a portion of the side surface where the surface pressure is applied by spacings between surface pressures which are extracted at each location in the ring radial direction by analysis (minute spacings in the ring radial direction). When the surface pressure distributions are converted into load distributions, the load distributions are further converted into friction force distributions (step S150). The conversion from a load distribution into a friction force distribution is performed by multiplying the load distribution by a predetermined coefficient of friction (e.g.,  $\mu=0.09$ ).

When the load distributions are thus converted into friction force distributions, resistance forces (anti-pitching moments)  $M_{rp}$  by a friction force which are exerted when the elements EL receive a force in a tangential direction of the sheave SH are calculated based on the friction force distributions (step S160). The anti-pitching moment  $M_{rp}$  is, as described above, a resistance force by a friction force which is exerted when the element EL tries to rotate about a pivot which is the location of the center (center of pitching O) of a load received by the second side surface FL of the element EL. In the present embodiment, as shown in FIG. 14, the calculation of the anti-pitching moment  $M_{rp}$  is performed by determining the center of pitching O such that an integrated value obtained based on distances of an outer friction force distribution in the belt radial direction of the second side surface FL with respect to the center of pitching O of the element EL from the center of pitching O and an integrated value obtained based on distances of an inner friction force distribution in the belt radial direction of the second side surface FL with respect to the center of pitching O from the center of pitching O are equal to each other in absolute value, and taking the sum of the two integrated values derived at that time (or one of the integrated value). In this manner, anti-pitching moments  $M_{rp}$  can be calculated in the analysis models for the plurality of elements EL having different flank angles.

Then, analysis conditions in which only input torque is changed are set (step S170), and stress analysis is performed with the set analysis conditions, by which a minimum principal stress  $a_1$  acting on a portion 51 between the saddle surface SS and an inner surface of a pillar part PL, and a minimum principal stress  $a_2$  acting on an edge part S2 (or a slightly inner side than the edge part S2) in a width direction of an edge of a body part BA which is on an opposite side to the saddle surface SS are derived (step S180). Here, in the setting of input torque which is set for stress analysis performed upon deriving minimum principal stresses  $a_1$  and  $a_2$ , maximum torque that can be inputted to the primary shaft from the engine when lock-up is off (upon stalling) is set. Namely, input torque set at step S120 as an analysis condition for stress analysis for deriving anti-pitching moments  $M_{rp}$  is smaller than input torque set at step S170 as an analysis condition for stress analysis for deriving minimum principal stresses  $a_1$  and  $a_2$ . The minimum principal stresses  $a_1$  and  $a_2$  mainly occur by a load directed toward the inner side in the belt radial direction and received by the saddle surface SS of the element EL from the ring, and are indices for determining the durability of the element EL. Thus, for the input torque set at step S170, it is desirable to consider torque obtained by multiplying maximum torque

that can be inputted to the primary shaft of the continuously variable transmission, i.e., engine's maximum torque, by the torque amplification factor of the torque converter. On the other hand, of the plurality of elements EL having different flank angles, an element EL having a flank angle with the largest anti-pitching moment  $M_{rp}$  becomes substantially parallel, on its second side surface FL, to a contact surface (inclined surface) of the sheave SH, with the element EL being deformed by the set input torque, and a bias in contact pressure (surface pressure) occurring when the second side surface FL receives a force from the sheave SH is reduced (torque transmission efficiency increases), and thus, it is desirable that the input torque set at step S120 be torque in a practical range. For such a reason, input torque set for stress analysis for deriving anti-pitching moments  $M_{rp}$  is set to be smaller than input torque set for stress analysis for deriving minimum principal stresses  $a1$  and  $a2$ . FIG. 15 is an illustrative diagram showing a relationship between transmittable torque and hydraulic pressure for the transmission belt 10 of the present embodiment and a transmission belt 310 of a comparative example, and FIG. 16 is a partial cross-sectional view of the transmission belt 310 of the comparative example. Note that the transmission belt 310 of the comparative example includes an element 320 having a substantially trapezoidal body part 321 having a pair of side surfaces 320s at both edges in a width direction, a substantially triangular head part 322 extending from a central portion in the width direction to a ring's outer circumference side, and a pair of depressed parts 323a and 323b that open outward in the width direction between the body part 321 and the head part 322; and a pair of layered rings 312a and 312b which are held in the pair of depressed parts 323a and 323b of the element 320. In the element 320 of the comparative example, inner surfaces in a ring radial direction of the pair of depressed parts 323a and 323b are saddle surfaces 323aa and 323sb. When transmission torque is relatively large, the element 20 of the present embodiment is more likely to be deformed by a load directed toward the inner side in the ring radial direction and received from the layered ring over the element 320 of the comparative example, and the coefficient of a friction force of the pair of second side surfaces 20sb significantly decreases. Due to this, when torque to be transmitted is relatively large, as shown in FIG. 15, hydraulic pressure to be supplied from the hydraulic control device is larger in the element 20 of the present embodiment than the element 320 of the comparative example. Hence, in the present embodiment, in order to prevent a shortage of hydraulic pressure which results from a reduction in the coefficient of a friction force when torque to be transmitted is relatively large, for input torque set at step S120, the largest torque  $T_{egmax}$  among torques in a practical range, i.e., torque obtained when lock-up is on (upon non-stalling), is set. Then, the element 20 is designed such that the coefficient of a friction force is the above-described predetermined coefficient of a friction force (e.g.,  $\mu=0.09$ ) at that time.

When an anti-pitching moment  $M_{rp}$  and two minimum principal stresses  $a1$  and  $a2$  are thus derived in each of the analysis models for the plurality of elements EL having different flank angles, a flank angle that is set for a model having the largest anti-pitching moment  $M_{rp}$  is determined to be an optimal flank angle  $\theta_{op}$  in a range in which either of the absolute values of the derived two minimum principal stresses (the compression side is negative)  $a1$  and  $a2$  does not exceed an allowable value (step S190). Then, a die (the shapes of a die plate, a punch, an ejector, and a pusher) is designed such that the flank angle is the optimal flank angle

bop (step S200), and a steel sheet (flat-shaped member) is stamped using the designed die, by which an element is formed (step S210), and the element is completed. FIGS. 17 to 19 show the states of formation of an element using a die. Note that in the drawings an open arrow with a solid line indicates a state of going up or down in an arrow direction, and an open arrow with a dashed line indicates a state of pressurizing in an arrow direction. First, as shown in FIG. 17, a die plate 31, an ejector 33, and a knock-out pin 35 are lifted until a top surface of a flat-shaped member P hits on bottom surfaces of a punch 32, a punch pin 36, and a pusher 34, with the bottom surfaces of the punch 32, the punch pin 36, and the pusher 34 being in the same plane. Subsequently, as shown in FIG. 17, a top surface of the ejector 33 is pressed against a bottom surface of the flat-shaped member P, and the top surface of the flat-shaped member P is pressurized downward by the punch 32 and the pusher 34. The punch 32 and the pusher 34 go up together with the flat-shaped member P by applied upward pressure from the ejector 33 while pressurizing the top surface of the flat-shaped member P downward, by which the punch pin 36 fixed so as not to be able to go up or down projects in a downward direction relative to the punch 32, and pressurizes the top surface of the flat-shaped member P downward at a tip part of the punch pin 36. By this, a tapered surface is formed on the bottom surface of the flat-shaped member P by the applied pressure from the ejector 33, and a depressed part is formed on the top surface of the flat-shaped member P by the applied pressure from the punch pin 36, along with which a material flows into a hole part 33h for formation of a protrusion, by which a protrusion is formed on the bottom surface of the flat-shaped member P. Then, as shown in FIG. 19, the pusher 34 pressurizes the top surface of the flat-shaped member P downward while the die plate 31 is lifted, by which the flat-shaped member P is held tight, and by further lifting the die plate 31, the flat-shaped member P is stamped out in an outline shape of an element. Since the shapes of the die plate 31, the punch 32, the ejector 33, and the pusher 34 are designed such that the flank angle of an element is an optimal flank angle  $\theta_{op}$  determined at the above-described step 190, deformation of the element upon torque transmission can be excellently suppressed, and the element capable of excellently suppressing local wear of a pair of second side surfaces can be obtained.

In the method for producing an element of the present embodiment, a flank angle set for a model having the largest anti-pitching moment  $M_{rp}$  is determined to be an optimal flank angle  $\theta_{op}$  in a range in which minimum principal stresses  $\sigma1$  and  $\sigma2$  do not exceed an allowable value in absolute value. However, depending on the shape or material of the element, without considering minimum principal stresses, a flank angle set for a model having the largest anti-pitching moment may be determined to be an optimal flank angle  $\theta_{op}$ . In addition, when there is another constraint about the flank surfaces of the element, a flank angle set for a model having the largest anti-pitching moment may be determined to be an optimal flank angle  $\theta_{op}$  in a range in which that another constraint is satisfied.

The method for producing an element of the present embodiment is applied to production (design) of an element 20 having a body part 21 including a saddle surface 23s that comes into contact with a layered ring 12; and a pair of pillar parts 22 extending from both sides in a width direction of the saddle surface 23s in the width direction. However, as shown in FIG. 16, the method can also be applied to production (design) of an element including a body part 321; a substantially triangular head part 322; and a pair of

depressed parts **323a** and **323b** that open outward in a width direction between the body part **321** and the head part **322**.

As described above, a transmission belt of the present disclosure is a transmission belt (**10**) that includes a plurality of elements (**20**) and a ring (**12**) that circularly puts together the plurality of elements (**20**), and that is wound around V-shaped grooves of a pair of pulleys (**3** and **5**) of a continuously variable transmission (**1**) to transmit power, and the main points are that the elements (**20**) each include a body part (**21**) including a saddle surface (**23s**) that comes into contact with the ring (**12**); a pair of pillar parts (**22**) extending from both sides in a width direction of the saddle surface (**23s**) in the width direction; and a pair of side surfaces (**20s**), the pair of side surfaces (**20s**) each include a first side surface (**20sa**) formed on a corresponding one of the pillar parts (**22**); and a second side surface (**20sb**) formed so as to continue from the first side surface (**20sa**), and located more on an inner circumference side of the ring (**12**) than the first side surface (**20sa**), a pair of the first side surfaces (**20sa**) each are formed so as to be inclined toward an inner side of a corresponding one of the pillar parts (**22**) with respect to an extending direction, from an inner circumference side to an outer circumference side of the ring (**12**), of a corresponding one of the second side surfaces (**20sb**) continuing from the first side surface (**20sa**), and a pair of the second side surfaces (**20sb**) is formed such that the second side surfaces (**20sb**) are spaced farther apart from each other as the second side surfaces (**20sb**) extend from the inner circumference side to the outer circumference side of the ring (**12**), and that an angle ( $\theta b$ ) formed between the pair of the second side surfaces (**20sb**) is larger by 0.2 to 0.8 degrees than an opening angle ( $\theta O$ ) of the V-shaped grooves of the pulleys (**3**, **5**).

In an element having a pair of pillar parts on both sides in a width direction of a saddle surface with which a ring comes into contact, upon torque transmission, a force (compression force) from a pulley acts on a pair of side surfaces and a force (tension) from the ring acts on a central portion in the width direction of the saddle surface from an outer circumference side to an inner circumference side of the ring. At this time, the element is significantly deformed by the force from the ring acting on the central portion in the width direction of the saddle surface toward the inner circumference side, and a bias occurs in contact pressure (surface pressure) between the pair of side surfaces and the pulley. As a result, the pair of side surfaces swings (itches) in a front-back direction when receiving a force in a tangential direction from the pulley, causing local wear in each side surface of the element. The inventors of the present application have found by study that by forming an element such that a pair of first side surfaces each are inclined toward an inner side of a pillar part with respect to an extending direction, from an inner circumference side to an outer circumference side of a ring, of a second side surface continuing from the first side surface, a pair of second side surfaces is spaced farther apart from each other as they extend from the inner circumference side to the outer circumference side of the ring, and an angle formed between the pair of second side surfaces is larger by 0.2 to 0.8 degrees than an opening angle of the V-shaped grooves of the pulleys, upon torque transmission, the pair of second side surfaces becomes substantially parallel to contact surfaces (inclined surfaces) of the pulley with the element being deformed, and a bias in contact pressure between the pair of side surfaces and the pulley occurring when the pair of side surfaces (second side surfaces) receives a force in a tangential direction from the pulley is reduced. By this, the

resistance force (anti-pitching moment) by friction between the element and the pulley can be increased, and pitching of the element is excellently suppressed, enabling to reduce local wear of the pair of side surfaces that come into contact with the V-shaped groove of the pulley.

In such a transmission belt of the present disclosure, an angle formed between a pair of the second side surfaces (**20sb**) may be larger by 0.2 to 0.6 degrees than the opening angle ( $\theta O$ ) of the V-shaped grooves of the pulleys (**3**, **5**). By doing so, the anti-pitching moment can be further increased, enabling to further reduce local wear of each side surface caused by pitching of the element.

In addition, in the transmission belt of the present disclosure, the elements (**20**) each may include locking edge parts (**25**) that allow an adjacent element (**20**) to come into contact with the element (**20**) so that the locking edge parts (**25**) serve as a pivot of rotation of the two elements (**20**), and a boundary (B) between the first side surface (**20sa**) and the second side surface (**20sb**) may be located more on the outer circumference side than the locking edge parts (**25**). By this, a contact area of the element with the pulley is increased, by which the anti-pitching moment can be further increased, enabling to further reduce local wear of the side surfaces caused by pitching of the element. In this case, the locking edge parts (**25**) each may be formed in convex curved surface shape on one of the front and back of the element (**20**), the convex curved surface shape allowing the element (**20**) to come into line contact with an adjacent element (**20**), an edge part (**25i**) on the inner circumference side of each of the locking edge parts (**25**) may be located more on the inner circumference side than the saddle surface (**23s**, T), an edge part (**25o**) on the outer circumference side of each of the locking edge parts (**25**) may be located more on the outer circumference side than the saddle surface (**23s**, T), and the boundary (B) between the first side surface (**20sa**) and the second side surface (**20sb**) may be located more on the outer circumference side than the edge part (**25o**) on the outer circumference side of the locking edge part (**25**). By doing so, a distance between the saddle surface in the radial direction of the transmission belt and a line of contact between elements during torque transmission can be further reduced, and thus, a difference in angular velocity between the ring and the element is reduced, by which local wear of the side surfaces caused by pitching of the element can be excellently reduced, and friction loss caused by relative sliding between the ring and the element can be excellently reduced.

Furthermore, in the transmission belt of the present disclosure, an edge part (**21ei**) on the inner circumference side of the body part (**21**) may be formed to be in flat shape in a width direction. By doing so, the stiffness of the element can be increased, and thus, deformation of the element is suppressed, enabling to excellently reduce local wear of the side surfaces caused by pitching of the element.

In addition, in the transmission belt of the present disclosure, a pair of hook parts (**22f**) that protrude in the width direction from free end parts of the pillar parts (**22**) so as to face each other may be further provided, and a retainer ring (**15**) may be disposed between the ring (**12**) and the hook parts (**22f**) of the plurality of elements (**20**).

Note that although in the present disclosure a mode of a transmission belt is described, a mode of a continuously variable transmission including any of the above-described transmission belts of the present disclosure can also be employed. In this case, an angle ( $\theta b$ ) formed between a pair of the second side surfaces (**20sb**) may be determined such that a pair of the second side surfaces (**20sb**) becomes

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substantially parallel to contact surfaces of the pulleys (3, 5) when torque is transmitted with a compression force being greater than or equal to a predetermined value, the compression force being exerted on the transmission belt (10) by the pulleys (3, 5).

In addition, although in the present disclosure a mode of a transmission belt is described, a mode of a method for designing an element included in a transmission belt can also be employed.

Specifically, a method for designing an element of the present disclosure is a method for designing a plurality of elements (20) of a transmission belt (10) that includes the plurality of elements (20) each including a body part (21), a pair of side surfaces (20s) located at both edges in a width direction of the body part (21), and a saddle surface (23s) located between the pair of side surfaces (20s) in the width direction; and a ring (12) that circularly puts together the plurality of elements (20) by an inner circumferential surface of the ring (12) coming into contact with each of the saddle surfaces (23s) of the plurality of elements (20), and that is wound around V-shaped grooves of a pair of pulleys (3, 5) of a continuously variable transmission (1) to transmit power, and the main points are that a pulleys' specification including an opening angle of the pulleys (3, 5), an elements' specification including flank angles, each being an angle formed between the pair of side surfaces (20s), and an analysis condition including input torque of the continuously variable transmission (1) are set, and by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, distributions of friction forces in a radial direction of the ring (12) exerted between the pair of side surfaces (20s) and the pulleys (3, 5) are derived for a plurality of different flank angles, rotational moments at the center of pitching of the elements (20) are derived for the plurality of flank angles from the friction force distributions derived for the plurality of flank angles, and a flank angle suitable for the continuously variable transmission (1) is determined based on the rotational moments derived for the plurality of flank angles.

In the method for designing an element of the present disclosure, a pulleys' specification including an opening angle of the pulleys, an elements' specification including flank angles, each being an angle formed between a pair of side surfaces, and an analysis condition including input torque of the continuously variable transmission are set, and by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, friction force distributions (distributions of friction forces in a ring radial direction) between the pair of side surfaces and the pulleys are derived for a plurality of different flank angles, rotational moments at the center of pitching of the elements are derived for the plurality of flank angles from the derived friction force distributions, and a flank angle suitable for the continuously variable transmission is determined based on the derived rotational moments. The rotational moment at the center of pitching of the element corresponds to a resistance force by a friction force exerted when the element receives a force from the pulley, and thus, by determining a flank angle based on the rotational moment, pitching of the element can be excellently suppressed, enabling to reduce local wear of the pair of side surfaces that come into contact with the V-shaped groove of the pulley.

In such a method for designing an element of the present disclosure, a flank angle at which the largest rotational moment is obtained may be determined to be a flank angle suitable for the continuously variable transmission in a range in which another constraint is satisfied. In this case, the

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elements (20) each may include a body part (21) including the saddle surface (23s); and a pair of pillar parts (22) extending from both sides in a width direction of the saddle surface (23s) in the width direction, by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, a minimum principal stress acting between the saddle surface (23s) and an inner surface of each of the pillar parts (22) and a minimum principal stress acting on an edge part in a width direction of an edge (21ei) of the body part (21) may be derived for the plurality of flank angles, the edge (21ei) being on an opposite side to the saddle surface (23s), and a flank angle at which the largest rotational moment is obtained may be determined to be a flank angle suitable for the continuously variable transmission (1) in a range in which either of the derived minimum principal stresses does not exceed an allowable value as the another constraint. By doing so, while the durability of the element is secured, pitching of the element is excellently suppressed, enabling to reduce local wear of the pair of side surfaces.

Furthermore, in this case, as the analysis condition used to derive the minimum principal stresses, the input torque may be set to maximum torque that can be inputted to the continuously variable transmission (1), and as the analysis condition used to derive the rotational moments, the input torque may be set to predetermined torque smaller than the maximum torque. Here, in a configuration in which torque from an engine is inputted to a continuously variable transmission through a torque converter with a lock-up clutch, the "maximum torque" may indicate maximum torque that can be inputted to the continuously variable transmission from the engine in a lock-up clutch off state, i.e., in a state in which torque is amplified by the torque converter, and the "predetermined torque" may be maximum torque that can be inputted to the continuously variable transmission from the engine in a lock-up clutch on state. In this case, while the durability of the element in the worst condition is secured, pitching of the element is excellently suppressed with torque in a practical range, enabling to reduce local wear of the pair of side surfaces.

In addition, in the method for designing an element of the present disclosure, by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, distributions of surface pressure in the radial direction received by the pair of side surfaces (20s) from the pulleys (3, 5) may be derived for the plurality of flank angles, and the surface pressure distributions derived for the plurality of flank angles may be converted into distributions of the friction forces in the radial direction.

Furthermore, in the method for designing an element of the present disclosure, a flank angle suitable for the continuously variable transmission (1) may be determined based on the rotational moments derived when the center of pitching is determined such that an integrated value obtained based on distances of an outer friction force distribution in the radial direction of the pair of side surfaces (20s) with respect to the center of pitching of each of the elements (20) from the center of pitching and an integrated value obtained based on distances of an inner friction force distribution in the radial direction of the pair of side surfaces (20s) with respect to the center of pitching from the center of pitching are equal to each other in absolute value. By doing so, a rotational moment matches a resistance force against pitching of the element, and thus, by determining a flank angle based on the rotational moment, pitching of the element can be more excellently suppressed.

In addition, in the present disclosure, a mode of a method for producing an element can also be employed.

Specifically, a method for producing an element of the present disclosure is a method for producing a plurality of elements (20) of a transmission belt (10) that includes the plurality of elements (20) each including a body part (21), a pair of side surfaces (20s) located at both edges in a width direction of the body part (21), and a saddle surface (23s) located between the pair of side surfaces (20s) in the width direction; and a ring (12) that circularly puts together the plurality of elements (20) by an inner circumferential surface of the ring (12) coming into contact with each of the saddle surfaces (23s) of the plurality of elements (20), and that is wound around V-shaped grooves of a pair of pulleys (3, 5) of a continuously variable transmission (1) to transmit power, and a pulleys' specification including an opening angle of the pulleys (3, 5), an elements' specification including flank angles, each being an angle formed between the pair of side surfaces (20s), and an analysis condition including input torque of the continuously variable transmission (1) are set, and by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, distributions of friction forces in a radial direction of the ring (12) exerted between the pair of side surfaces (20s) and the pulleys (3, 5) are derived for a plurality of different flank angles, rotational moments at the center of pitching of the elements (20) are derived for the plurality of flank angles from the friction force distributions derived for the plurality of flank angles, a flank angle suitable for the continuously variable transmission (1) is determined based on the rotational moments derived for the plurality of flank angles, a die (31 to 34) is formed based on the determined flank angle, and outside shapes of the elements (20) are formed by performing press working using the formed die (31 to 34).

Although the embodiments of the present disclosure have been described above, the present disclosure is not limited whatsoever to such embodiments and can, of course, be implemented in various modes without departing from the spirit and scope of the present disclosure.

#### INDUSTRIAL APPLICABILITY

The various aspects of the present disclosure can be used in manufacturing industries for transmission belts and continuously variable transmissions, etc.

The invention claimed is:

1. A method for designing a plurality of elements of a transmission belt that includes the plurality of elements each including a body part, a pair of side surfaces located at both edges in a width direction of the body part, and a saddle surface located between the pair of side surfaces in the width direction; and a ring that circularly puts together the plurality of elements by an inner circumferential surface of the ring coming into contact with each of the saddle surfaces of the plurality of elements, and that is wound around V-shaped grooves of a pair of pulleys of a continuously variable transmission to transmit power, the method comprising:

setting a pulleys' specification including an opening angle of the pulleys, an elements' specification including flank angles, each being an angle formed between the pair of side surfaces, and an analysis condition including input torque of the continuously variable transmission, and deriving, for a plurality of different flank angles, distributions of friction forces in a radial direction of the ring exerted between the pair of side surfaces

and the pulleys, by analysis based on the pulleys' specification, the elements' specification, and the analysis condition;

deriving, for the plurality of flank angles, rotational moments at a center of pitching of the elements from friction force distributions derived for the plurality of flank angles; and

determining a flank angle suitable for the continuously variable transmission, based on the rotational moments derived for the plurality of flank angles.

2. The method for designing a plurality of elements according to claim 1, comprising determining a flank angle at which a largest rotational moment is obtained to be a flank angle suitable for the continuously variable transmission, in a range in which another constraint is satisfied.

3. The method for designing a plurality of elements according to claim 2,

wherein

the elements each include a body part including the saddle surface; and a pair of pillar parts extending from both sides in a width direction of the saddle surface in the width direction, and

the method comprises:

deriving, for the plurality of flank angles, a minimum principal stress acting between the saddle surface and an inner surface of each of the pillar parts and a minimum principal stress acting on an edge part in a width direction of an edge of the body part, by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, the edge being on an opposite side to the saddle surface; and

determining a flank angle at which a largest rotational moment is obtained to be a flank angle suitable for the continuously variable transmission, in a range in which either of the derived minimum principal stresses does not exceed an allowable value as the another constraint.

4. The method for designing a plurality of elements according to claim 3, comprising:

setting the input torque to maximum torque that can be inputted to the continuously variable transmission, as the analysis condition used to derive the minimum principal stresses; and

setting the input torque to predetermined torque smaller than the maximum torque, as the analysis condition used to derive the rotational moments.

5. The method for designing a plurality of elements according to claim 1, comprising deriving, for the plurality of flank angles, distributions of surface pressure in the radial direction received by the pair of side surfaces from the pulleys, by analysis based on the pulleys' specification, the elements' specification, and the analysis condition, and converting surface pressure distributions derived for the plurality of flank angles into distributions of the friction forces in the radial direction.

6. The method for designing a plurality of elements according to claim 1, comprising determining a flank angle suitable for the continuously variable transmission, based on the rotational moments derived when the center of pitching is determined such that an integrated value obtained based on distances of an outer friction force distribution in the radial direction of the pair of side surfaces with respect to the center of pitching of each of the elements from the center of pitching and an integrated value obtained based on distances of an inner friction force distribution in the radial direction of the pair of side surfaces with respect to the center of pitching from the center of pitching are equal to each other in absolute value.

7. A method for producing a plurality of elements of a transmission belt that includes the plurality of elements each including a body part, a pair of side surfaces located at both edges in a width direction of the body part, and a saddle surface located between the pair of side surfaces in the width direction; and a ring that circularly puts together the plurality of elements by an inner circumferential surface of the ring coming into contact with each of the saddle surfaces of the plurality of elements, and that is wound around V-shaped grooves of a pair of pulleys of a continuously variable transmission to transmit power, the method comprising:

setting a pulleys' specification including an opening angle of the pulleys, an elements' specification including flank angles, each being an angle formed between the pair of side surfaces, and an analysis condition including input torque of the continuously variable transmission, and deriving, for a plurality of different flank angles, distributions of friction forces in a radial direction of the ring exerted between the pair of side surfaces and the pulleys, by analysis based on the pulleys' specification, the elements' specification, and the analysis condition;

deriving, for the plurality of flank angles, rotational moments at a center of pitching of the elements from friction force distributions derived for the plurality of flank angles;

determining a flank angle suitable for the continuously variable transmission, based on the rotational moments derived for the plurality of flank angles;

forming a die based on the determined flank angle; and forming outside shapes of the elements by performing press working using the formed die.

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